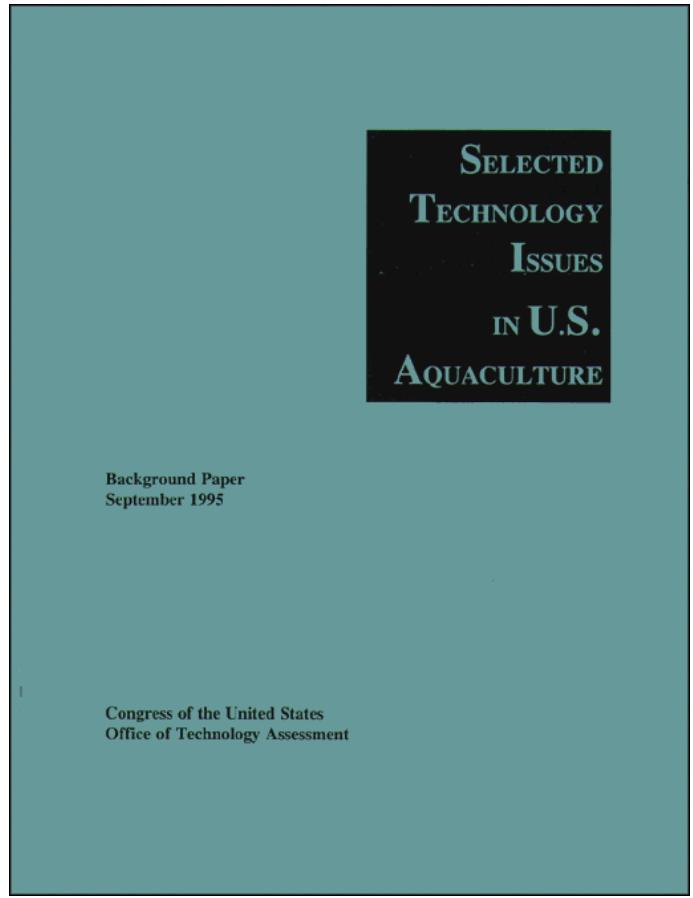
Selected Technology Issues in U.S. Aquaculture

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Foreword

As U.S. capture fisheries are declining, interest in aquaculture is again growing. Private, commercial aquaculture--the production of aquatic organisms (finfish, shellfish, and plants) by one or more individuals or corporate bodies that have owned them through all or part of their rearing period--is being considered for its potential to provide employment and income to declining coastal and rural communities, to help improve the U.S. balance of trade, and to provide consumers with a plentiful, safe, and nutritious protein source.

The United States lacks a strong national aquaculture policy and supporting federal presence. Over the years, levels and focii of agency involvement in aquaculture development have shifted in response to legislation and its differing interpretations. The National Aquaculture Act (NAA), the primary piece of aquaculture-related legislation, is slated for reauthorization in 1995 as part of the Farm Bill. One issue that underlies reconsideration of the NAA and related legislation is the federal role in research and regulation of this emerging industry.

Congress requested this Background Paper to provide information on technology issues of immediate importance to the U.S. aquaculture industry. This is a companion piece to the Background Paper on *Current Status of Federal Involvement in U.S. Aquaculture.* Committees requesting the assessment were the House Committee on Merchant Marine and Fisheries (since disbanded), the House Committee on Agriculture and its Subcommittee on Livestock, and the Senate Committee on Governmental Affairs.

OTA greatly appreciates the contributions of the Advisory Panel, authors of contracted papers, workshop participants, federal liaisons, and the many additional people who reviewed material for the report or gave valuable guidance. Their timely and in-depth assistance allowed us to explore some of the complex issues related to the federal role in aquaculture. As with all OTA studies, the content of this report is solely the responsibility of OTA.

ROGER C. HERDMAN
Director

HIGHLIGHTS

CHAPTER 2: AQUATIC ANIMAL HEALTH

- Disease is responsible for major economic losses to aquaculture, making disease prevention and treatment a critical need for the industry and an important focus for research needed to support aquaculture development.

- Approaches to prevention include good husbandry and management to minimize stress and exposure to pathogens; vaccines, if available; and culture of disease-resistant or certified disease-free stocks.

- Inadequate resources for disease treatment impedes the growth of aquaculture. Few approved drugs are available, and those that exist are targeted to specific organisms and diseases. Veterinary and diagnostic services are patchily available nationwide, and many states lack adequate resources of this kind. The expertise involved in introducing and gaining regulatory approval of new aquaculture drugs and the small market for these drugs discourage pharmaceutical industries from pursuing their development.

- Federal regulations regarding aquatic animal health treatment attempt to serve many goals: protection of aquatic animals (cultured and wild), human consumers, and the environment.

- Greater coordination of agencies and programs with a stake in aquatic animal health in aquaculture can improve performance with respect to regulatory goals. Changes in the new drug approval process could remove a significant impediment to industry development.

CHAPTER 3: BIOTECHNOLOGY

- Use of biotechnology in aquaculture is an essential tool in the maintenance and growth of the aquaculture industry. Established methods will continue to be important; new techniques may permit increased production and other benefits with costs and potential for adverse effects that must be evaluated carefully.

- Federal policy and regulations regarding biotechnology have developed in response to risk and safety issues that arise in aquaculture as well as other industries that might benefit economically from manipulating plant and animal characteristics. However, many genetically modified aquatic organisms do not fall under the umbrella of any legislation. Transgenic aquatic organisms also pose special problems for regulators because they may cross national boundaries.

- The risks and benefits of developing aquatic transgenics are subjects of considerable controversy, signaling the need for further research. In addition to risk/benefit analyses, critics call for exploration of numerous moral and ethical issues related to the use of biotechnology in the aquaculture industry.

CHAPTER 4: BIRD PREDATION

- Bird predators can cause significant economic problems at some aquaculture facilities. Accurate data to document their toll and to establish relationships between facility type/species and losses to predation are scant, making it difficult to design effective controls.

- Responsibility for regulation and monitoring activities related to predation at aquaculture facilities lies with several federal agencies and state governments. Coordination among all governing bodies sometimes is not apparent; record-keeping is cumbersome and lacks systematic collection and ready access.

- Possible impacts of aquaculture and of attempts at predator control on predator population trends are poorly understood. Data are lacking to assess population trends and cause/effect relationships.

- Given the lack of knowledge and data on predator levels, behaviors and population trends; and in light of the diversity of aquaculture operations, a multifaceted and integrated approach to predator control may be most effective. This would involve combining several deterrents used in rotation with the understanding that complete elimination of predation problems is unrealistic. Reducing losses to economically tolerable levels is the only feasible goal.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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1
Introduction

BACKGROUND

Aquaculture has a long history of supplying protein and other products around the world, but a short history of commercial production in the United States (box 1-1). Until the 1950s, aquatic species were produced mainly to supply fish restocking programs, to provide baitfish and sportfish for fee fishing operations, and for direct family consumption; little reached commercial markets. Although trout had been produced for food since the turn of the century, only with the advent of the catfish culture industry did commercial aquaculture gain visibility as a market force.[1]

Hundreds of different aquatic species are produced in the United States, including various animal and plant ornamentals, species for environmental remediation, industrial and pharmaceutical feedstocks, and products for biomedical research. Although as many as 30 are commonly cited aquacultural species, fewer than 10 species make up most of U.S. aquacultured food production: catfish, trout, crawfish, salmon, hybrid striped bass, tilapia, and various mollusks (table 1-1).

Aquaculture is practiced in every U.S. state and territory, from Atlantic salmon off the coast of Maine to alligators in Louisiana to giant clams on the Pacific islands of Micronesia. Production systems are similarly diverse, ranging from nearshore bottom "seeding" of mollusks to expansive open ponds to high-tech water recirculating systems in warehouses to integrated systems cycling nutrients among land- and water-based production systems.

Today, aquaculture is touted as the fastest growing segment of U.S. agriculture, based on a fourfold increase in domestic output of fish, shellfish, and aquatic plants between 1980 and 1990 (61). By 1993, USDA estimated that the value of U.S. aquaculture products had reached $760 million (57). Domestic aquaculture production currently accounts for about 10 to 15 percent of the U.S. seafood supply.

Aquaculture products as a proportion of total seafood consumption is gradually rising, likely reflecting increasing availability (e.g., year-round supply) and favorable prices compared to wild caught seafood. This also may portend growing consumer recognition of the nutritional value of seafood in general and confidence in the quality of aquacultured products in particular. Hopes for aquaculture as a growth industry, especially for economically troubled rural and coastal communities, remain high.

The National Aquaculture Act was slated for reauthorization in 1993, but agreement on certain provisions was not reached prior to debate on the 1995 Farm Bill. The Administration's 1995 Farm Bill Proposal includes reauthorization of the National Aquaculture Act with several amendments (144). Also currently pending reauthorization are the Regional Aquaculture Centers, the National Research Initiative, and other USDA programs that do or could support aquaculture development. Determination of the future functions and funding of the National Sea Grant College Program, the National Marine Fisheries Service, and the Fish and Wildlife Service are also on the legislative agenda.

[1] For additional information on the historical development of aquaculture in the United States, see R.R. Stickney, *A History of Aquaculture in the United States* (New York, NY: John Wiley & Sons, in press).

BOX 1-1: Definitions of Terms Used in This Background Paper

Definitions of certain terms used in the background paper are based on current common usage or on the specific request of the congressional requesting committees as discussed below:

Aquaculture: For the purposes of this analysis, aquaculture will include only production of aquatic organisms (finfish, shellfish, and plants) that have been owned by one or more individuals or corporate bodies throughout their rearing period. Practices that include controlled rearing of aquatic organisms during only one part of their life cycle but that are exploitable at any time by the public as a common property resource (e.g., private ocean ranching, commercial and recreational enhancement stocking, and "fattening" of captured stock) were excluded by request of the congressional requesting committees, and are not considered here.

Fish: Unless specified, the term fish is used to include finfish and shellfish. It does not include aquatic plants, reptiles, or amphibians.

Mariculture: Aquaculture operations that take place in nearshore or offshore waters. Under this definition, mariculture does not include on-land aquaculture using pumped or artificial seawater.

Offshore Aquaculture: Aquaculture operations that are undertaken in federal waters of the Exclusive Economic Zone, generally the zone from three to 200 miles off the coast of U.S. states and territories.

Seafood: Unless specified, the term seafood includes edible products derived from fresh- and salt-water species.

Stock Enhancement: Programs designed to increase the stock of fish for exploitation by the public as common property resources are considered stock enhancement programs. These may include efforts to increase stocks for recreational or commercial purposes. Enhancement goals and programs are not included in this analysis.

The federal government has made a commitment through the National Aquaculture Act to support development of a private aquaculture industry.[2] Of immediate concern to established sectors of this industry are technologies affecting aquatic animal health, products of biotechnology, and controlling predation in aquaculture facilities. Loss of aquaculture production to disease and predation are major problems for the industry.

Technologies that help to address these issues may help to increase the profitability of the industry. Similarly, application of biotechnology may yield faster growing or more disease resistant organisms and other benefits. However, the implementation of technological interventions in these areas require careful evaluation to prevent possible adverse consequences to human health or the environment.

AQUATIC ANIMAL HEALTH MANAGEMENT

Aquatic animals in the United States. are affected by numerous diseases which lead to substantial economic losses by the U.S. aquaculture industry (70). Total losses attributed to disease varies from year to year and among species; reported losses have ranged from $2.5 million (trout 1988) to $23 million (catfish 1989) (88,89). including good husbandry and management to minimize stress and exposure to pathogens; vaccines, if available; and culture of disease-aresistant or certified disease-free stocks.

A single disease can wipe out an entire aquaculture crop, implying that it is economically prudent to maintain production system health. Profligate use of chemical treatments, on the other hand, may affect consumer safety or the environment. For

[2] For an analysis of federal involvement in aquaculture, see U.S. Congress, Office of Technology Assessment, *Current Status of Federal Involvement in U.S. Aquaculture* OTA-BP-ENV-170 (Washington, DC: Office of Technology Assessment, September, 1995).

example, chemicals and antibiotics used in health management can leave residues in cultured and wild organisms, leading to potential health problems for consumers, as well as harming the environment and potentially creating antibiotic resistant strains of pathogens. Chemical use may be minimized by technologies that prevent disease including good husbandry and management to minimize stress and exposure to pathogens; vaccines, if available; and culture of disease-resistant or certified disease-free stocks.

TABLE 1-1: Production Data for Representative Species Cultured in the U.S.

Common name	Scientific name	1992 Production	
		Volume[a]	Value[b]
Mollusks			
• American Oyster	*Crassostrea virginica*	83,544 mt	$82,432,000
• Pacific Oyster	*Crassostrea gigas*	31,202 mt	
• Blue Mussel	*Mytilus edulis*	639 mt	$1,162,000
• Quahog clam	*Mercenaria mercenaria*	6,371 mt	
• Japanese littleneck clam	*Venerupis japonica (*also *Tapes japonica)*	1,920 mt	$11,539,000
Crustaceans			
• Shrimp (marine)	*Penaeus spp.*[c]	2,000 mt	$17,637,000
• Red Swamp crawfish	*Procambarus clarkii*	28,591 mt	$34,860,000
Finfish			
• Channel catfish	*Ictalurus punctatus*	207,460 mt	$273,506,000
• Atlantic salmon	*Salmo salar*	10,028 mt	$75,193,000
• Rainbow trout	*Oncorhynchus mykiss*[d]	26,057 mt	$53,942,000
• Carps	*Cyprinus spp.*	1,659 mt	n/a
• Tilapia	*Tilapia spp.*	4,082 mt	n/a
• Hybrid striped bass	*Morone chrysops x M. saxatilis*	n/a	n/a
Other/Miscellaneous[e]			$173,916,000
TOTAL			**$724,187,000**

[a] A metric ton is equal to 1.102 tons.

[b] Products are aggregated by general type (e.g., oyster, clam) and may include species other than those presented here.

[c] The most commonly cultured marine shrimp in the United States is *Penaeus vannamei*, also known as the Vanna White shrimp.

[d] Formerly *Salmo gairdneri*; data include freshwater and saltwater trout production.

[e] Miscellaneous species include hybrid striped bass, tilapia, and nonfood products such as ornamental fish, aquatic plants, and baitfish.

SOURCES: Office of Technology Assessment, 1995; (volume data) United Nations, Food and Agriculture Organization, Fisheries Department, "Aquaculture Production 1986-1992" FAO Fisheries Circular No. 815 Revision 6, (Rome, Italy: UNFAO, 1993); (value data) National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fisheries Statistics Division,"Fisheries of the United States--1993" (Washington, DC: U.S. Department of Commerce, 1993).

BIOTECHNOLOGY

Many biotechnologies used in aquaculture are developed to increase production, reduce costs of production, manage disease outbreaks, raise the value of currently cultured organisms, or result in the culture of new species. However, use of these technologies may pose risks to human health or the environment or conflict with moral and ethical values. Therefore, increasing use of biotechnologies in aquaculture is of concern to Congress. Currently, federal oversight of some aquatic genetically modified organisms (GMOs)[3] is fragmented among several federal agencies, while other aquatic GMOs receive no federal oversight. Although several federal agencies have developed guidelines or promulgated regulations governing use of GMOs, new legislation specifically addressing the use and release of aquatic GMOs may be needed to minimize potential adverse impacts on the environment and human health and safety (74).

BIRD PREDATION

Potential predators of aquacultural crops include piscivorous birds, marine mammals, fish, turtles, sea snakes, and squid (9). Predation problems can arise in virtually any type of aquacultural endeavor except those where cultured stocks are contained indoors or in sealed holding structures (i.e., "enclosed system" operations). Often predatory animals may be protected by law making lethal methods to reduce predation unacceptable unless a permit is obtained and lethal control is combined with non-lethal methods. Technologies are needed that efficiently and economically reduce crop loss without significantly affecting predator populations or their roles in ecosystem health.

Facility design may make certain operations especially vulnerable to predation problems (107). Large ponds are difficult and expensive to cover with overhead netting. Gently sloping embankments of ponds may closely resemble natural feeding sites and are attractive to foraging by wading predators. Unprotected containment units or flow-through raceways provide predators good feeding platforms or access to stocks, and thus these areas can be subject to predation problems. Nearshore off-bottom culture is subject to both bird and marine mammal predation problems. Special precautions must be taken to prevent predation from below the water's surface (e.g., by seals).

The federal government already has established roles in development and regulation of technologies affecting aquatic animal health, biotechnology, and predation. The following chapters examine these three topic areas and related congressional interest, issues, and technological developments. Enhancing aquatic animal health management, expanding use of biotechnology, and developing more effective predation control methods could support accelerated expansion of the aquaculture industry by increasing production and profits for producers, ensuring safety to consumers, and maintaining or improving environmental quality.

[3] Defined in chapter 3.

2
Aquatic Animal Health

At least 50 different diseases currently affect aquatic animals resulting in high economic losses by the U.S. aquaculture industry each year (70). In 1988 for example, the trout industry cited losses due to disease at $2.5 million; in 1989 the catfish industry reported loss due to disease at $23 million (88,89). A viral epidemic in Texas destroyed an estimated $11 million worth of shrimp in a short period of time in 1995 (149).

Diseases may be caused by many different factors including poor environmental conditions and exposure to infectious agents. Polluted water, contaminants in feed, and various viruses, fungi, bacteria, and parasites are capable of causing disease outbreaks in cultured organisms. Disease outbreaks often occur when poor conditions causing stress are combined with the presence of opportunistic pathogens (134).

Preventing stress in cultured organisms is essential for maintaining healthy populations. Stress weakens the immune system and allows disease organisms to multiply and gain a foothold (134). Stress may be caused by physical damage to the organism, crowding, handling, and poor water quality conditions such as widely fluctuating water temperatures, low dissolved oxygen levels, and high ammonia concentrations (134). Strategies for controlling disease outbreaks rely on good husbandry as well as treatment (127).

CONGRESSIONAL INTEREST

Four major areas of congressional interest in aquatic health management include existing legislation governing interstate transport of aquaculture products, federal regulation regarding use of drugs for cultured organisms, funding and research priorities, and protection of public health and the environment.

Several existing laws directly affect health management in aquaculture. One of the most controversial laws is the Lacey Act (16 U.S.C. 667 et seq., 18 U.S.C. 42 et seq.). Among other goals, this law attempts to restrict the movement of certain pathogens into the United States and into watersheds where a pathogen is not currently found by regulating the movement of fish and wildlife. In addition to a federal list of prohibited fish, wildlife, and pathogens, individual states develop lists of prohibited species to suit their own needs and additionally may require aquaculture products to be certified as disease free for specific pathogens before they can cross state lines. The result is a patchwork of regulation that may impede the movement of aquacultural products.[1]

Similarly, drugs used in aquaculture (box 2-1) must meet numerous safety and efficacy requirements and be approved by the Food and Drug Administration. This process is expensive and approval only can be granted for the specific drug application and species for which the data were generated. This system has resulted in the approval of five drugs for legal use in aquaculture, four of which are currently available (table 2-1). Members of the industry contend that this is too few drugs to address a wide range of potential disease problems and that the risk of catastrophic loss inhibits expansion of the industry (131).

[1] Federal and state roles in the Lacey Act are covered in more depth in the OTA publication, *Harmful Non-Indigenous Species in the United States*, OTA-F-565 (Washington, DC: U.S. Government Printing Office, September 1993).

BOX 2-1: Health Related Definitions

Antibiotic: Substance that may inhibit the growth of or destroy microorganisms and is widely used to prevent or treat diseases.

Bacteria: One-celled microorganisms that have no chlorophyll, multiply by simple division, and can be seen only with a microscope.

Best management practices: Husbandry practices that strive to ensure optimal health, production, and economic performance with minimal adverse environmental impact.

Biologics: Category of health intervention tools which include vaccines and diagnostic test kits.

Chemical prophylaxis: Chemical treatment to reduce disease-causing organisms before outbreak occurs.

Drug: An article that is intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in humans or other animals; an article (other than food) intended to affect the structure or any function of the body of humans or other animals.

Extra-label use: The use of an approved new animal drug in a manner that is not in accordance with the approved label directions.

Investigational new animal drug (INAD) exemption: Exemption authorized under the Federal Food, Drug, and Cosmetic Act to permit the shipment of new animal drugs in interstate commerce without an approved new animal drug application.

Low regulatory priority (LRP) substance: Unapproved new animal drug for which FDA has a policy of regulatory discretion that allows the use of such a substance without an approved new animal drug application or INAD (Investigational New Animal Drug) exemption.

New animal drug: Any drug intended for use in animals other than people, the composition of which is not generally recognized among experts qualified by scientific training and experience as safe and effective for use under the conditions prescribed, recommended, or suggested in its labeling.

New animal drug application (NADA): An application package submitted to FDA for review that requests the approval of a new animal drug. The application includes sufficient data to establish the safety and effectiveness of the drug product, along with other requirements.

Parasite: A plant or animal that lives on or in an organism of another species from which it derives sustenance or protection without benefit to, and usually with harmful effects on, the host.

Pathogen: Any agent, especially a microorganism, able to cause disease.

Pesticide: Any substance or mixture of substances intended for preventing, destroying, or repelling any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant.

Pharmacokinetics: The study of the absorption, metabolism, and action of drugs.

Prescription (Rx) drug: An animal drug for which adequate directions for safe and effective use by a lay-person cannot be written and which therefore must be prescribed by a licensed veterinarian. The label bears the statement, "Caution: Federal law restricts this drug to use by or on the order of a licensed veterinarian."

Registration: Under the Federal Insecticide, Fungicide, and Rodenticide Act, the formal listing with EPA of a new pesticidal active ingredient prior to its marketing or distribution in intra- or interstate commerce.

Specific Pathogen Free (SPF): Organism certified free of specific pathogens.

Therapeutant: Term used interchangeably with the word drug; not used by the FDA.

Tissue residue: The drug, pesticide, or toxic breakdown product remaining in edible tissue after natural or technological processes of removal or degradation have occurred.

Box 2-1: (Continued)

Tolerance: The maximum amount of pesticide or drug residue allowed by law to remain in or on a harvested crop or food animal product. EPA sets tolerances for pesticides and FDA sets tolerances for drugs so that treated crops or animals consumed do not pose an unreasonable risk to consumers. Tolerances are set for food-use crops on a per-crop basis. Tolerances are set for animal products on the basis of individual species and tissue (muscle, liver, etc.).

Vaccine: A preparation of killed microorganisms; living attenuated, fully virulent, or related nonvirulent microorganisms; or parts of micro- or macroorganisms that are administered to produce or increase immunity to a particular disease.

Virus: Particles that are composed of genetic material (RNA or DNA) and a protein coat. Viruses can infect animals, plants, and, bacteria. Viruses only can reproduce within living cells.

Withdrawal time: The minimum required period of time between the last drug treatment of an animal and the slaughter or release of that animal.

SOURCES: Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production, in cooperation with the Extension Service, *Guide to Drug, Vaccine, and Pesticide Use in Aquaculture*, (Washington, DC: U.S. Department of Agriculture, 1994); G. Stefan, Chief of Industry Programs, Center for Veterinary Medicine, Food and Drug Administration, Rockville, MD; and Webster's New World Dictionary, Third College Ed., V. Neufeld and D.B. Guralink (eds.) (New York, NY: Simon & Schuster, Inc., 1988).

Establishing priorities for aquatic animal health management research, evidenced by the formation of a JSA task force, is another major area of congressional interest. Some have argued that this research is conducted without adequate attention to industry concerns. Others believe that more funding should be provided for extension services, diagnostic facilities, and especially for research to obtain new drug approvals.

Congress also may be interested in aquatic health management to ensure adequate protection of public health. Chemicals and antibiotics used in health management can leave residues in cultured and wild organisms, leading to health problems for consumers as well as harming the environment, and potentially creating antibiotic resistant strains of pathogens. Consumption of products containing antibiotic residues can lead to direct human health problems. For example, the antibiotic chloramphenicol[2] may cause aplastic anemia (a dangerous blood disorder) in some individuals (16). Other antibiotics can cause allergic reactions ranging from a mild skin rash to potentially fatal responses.

Human consumption of low levels of antibiotics, as residues in fish tissue, may contribute to development of antibiotic resistant pathogenic organisms. For example, a bacterial species which causes disease in fish may become resistant to antibiotics and pass this resistance on to human pathogenic bacteria. Such bacteria may be potentially untreatable when they cause disease in humans.[3] It is suspected that long-term, low level exposure of bacteria to an antibiotic may contribute to development of resistance to that antibiotic in that bacterial population. Because of these concerns, antibiotic use must be restricted to approved uses, in accordance with approved dosages, and with adherence to approved withdrawal times before slaughter, to preclude residues in edible tissue (45).

[2] Residues of this chemical have been found in imported shrimp, but it is not used in aquaculture in the U.S. (110).

[3] For more information on problems associated with antibiotic resistant bacteria see the OTA publication, *Impacts of Antibiotic Resistant Bacteria* (Washington, DC: OTA, September 1995).

Thus, if drugs are used as prescribed, residue levels in cultured organisms should not pose health risks (150). Antibiotic use, however, was found to vary by orders of magnitude at different salmon farms in Puget Sound (150). In areas where antibiotics have been used in large quantities, problems have arisen when wild organisms in the vicinity of aquaculture facilities have eaten large amounts of medicated feeds, or taken in excessive antibiotics by filter feeding. Wild fish and mussels caught near net-pen facilities in Norway and red rock crabs caught near net-pens in Puget Sound have had antibiotic concentrations exceeding accepted tolerance levels (84,150). Therefore, consumption of wild fish harvested from the vicinity of net pens may pose human health concerns. Quality

TABLE 2-1: FDA-Approved New Animal Drugs as of July 1995

Trade name	Active drug	Species	Uses
Finquel (MS-222)	Tricaine methanesulfonate	Ictaluridae, Salmonidae, Esocidae, and Percidae. (In other fish and cold-blooded animals, the drug should be limited to hatchery or laboratory use.)	Temporary immobilization (anesthetic)
Formalin-F[a] Paracide-F Parasite-S	Formalin	Trout, salmon, catfish, large-mouth bass, and bluegill	Control of external protozoa and monogenetic tremotodes
		Salmon, trout, and esocid eggs	Control of fungi of the family Saprolegniacae
		Cultured penaeid shrimp	Control of external protozoan parasites
Romet 30	Sulfadimethoxine and ormetoprim	Catfish	Control of enteric septicemia
		Salmoids	Control of furunculosis
Sulfamerazine in fish grade[b]	Sulfamerazine	Rainbow trout, brook trout, and brown trout	Control of furunculosis
Terramycin for fish	Oxytetracycline	Catfish	Control of bacterial hemorrhagic septicemia and pseudomonas disease
		Lobster	Control of gaffkemia
		Salmonids	Control of ulcer disease, furunculosis, bacterial hemorrhagic septicemia, and pseudomonas disease
		Pacific salmon	Marking of skeletal tissue

[a]Only Parasite-S is approved for use in shrimp. Formalin-F and Paracide-F are not approved for use in shrimp (45).
[b]According to sponsor, this drug is not presently being distributed.

SOURCE: Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production, in cooperation with the Extension Service, *Guide to Drug, Vaccine, and Pesticide Use in Aquaculture*, (Washington, DC: U.S. Department of Agriculture, 1994).

assurance programs and educational efforts to ensure proper use of antibiotics in the United States attempt to address these problems.

ISSUE IDENTIFICATION

Issue: Establishing Best Management Practices

Good husbandry is a critical factor in managing aquatic animal health. Maintaining proper environmental conditions, selecting healthy organisms, providing a nutritious diet, reducing stress, vaccinating organisms, and rapidly diagnosing, isolating, and treating disease outbreaks all are important aspects of good husbandry. Establishing consistent procedures or Best Management Practices (BMPs) for aquaculture operations may facilitate aquatic health management (120). BMPs, however, will be most effective for systems where control of environmental conditions is more complete, as in recirculating systems. In other systems such as outdoor ponds, where it is more difficult to control environmental parameters, BMPs may be more difficult to identify and implement. For example, research needed to determine water quality management procedures usually is performed in a particular type of pond. Ponds where the research is conducted often have uniform areas, depths, are of the same hydrological type, and generally have similar watersheds (14). Procedures that work well in specific experimental units may yield different results when used in ponds that are physically different. It may be difficult to produce BMPs that are applicable to a wide range of situations due to the large variability from system to system, even from one pond to another (14).

Although many species are raised in U.S. commercial aquaculture, details about their lifecycles, nutritional requirements, environmental tolerances, and diseases are commonly unknown, making it difficult to devise BMPs. Even for species such as catfish, salmon, trout, and oysters, information may be lacking.

Few reliable data exist on the impact of diseases in aquaculture production. Even the precise number of organisms a producer begins with may be unknown. For example, when an aquaculture producer begins an operation with fry or fingerlings, they are often packaged by weight and the producer may never know the exact numbers of organisms purchased. Harvested organisms also may be sold by weight and not number. Stocking ponds that contain organisms left from the previous crop may further complicate precise estimates of numbers of organisms contained in a pond (80). In addition, high losses in early life stages lead many aquaculturists to start the production cycle with fertilized eggs in excess of what they require for final production. High mortality in early production phases is typically accepted as part of the process and, thus, causes may never be fully investigated (89).

In some circumstances, loss of organisms can be attributed to specific causes such as escape of organisms, a natural disaster, or predation. However, it is usually difficult to determine all the reasons for loss of organisms before harvest especially when the number of organisms at the beginning, middle, and end of the cycle has never been accurately measured (80,89).

Issue: Availability of Health Products and Services

Managing the health of aquatic organisms is facilitated by veterinarians, aquatic animal health specialists, diagnostic labs, and specific products such as vaccines. Provision of services and distribution of products, however, is not uniform nationwide. Availability is likely to be high in areas with established aquaculture industries, but low in areas with fewer aquaculture facilities.

Aquatic health management would be facilitated by greater use and availability of appropriately trained veterinarians, diagnostic

and extension services. Veterinarians are important because they are the only people legally able to prescribe antibiotics or make provisions for extra-label drug use (use beyond that described in the drug's initial license). Currently, there is a shortage of veterinarians trained in managing the health of aquatic organisms. A survey conducted in 1993 found that only 17 of 35 states had private or public veterinarians that specialized in aquatic animal health (143). Interest in aquatic health management, however, is on the rise. Twenty four of the thirty one American Veterinary Medical Association (AVMA) accredited veterinary schools in North America now offer classes in aquatic medicine (113). By 1992, thirty seven percent of all graduating veterinary students had taken at least introductory courses in aquatic medicine. Some schools require students to enroll in aquatic medicine classes (113). As opportunities to practice aquatic medicine increase, more students are likely to become interested in this field.

The use and availability of diagnostic services also may be a factor in aquatic health management. Diagnostic, laboratory, and extension services are offered by some federal agencies (for example, APHIS or FWS), by state agencies including state veterinary schools, and in some cases laboratories that offer traditional services for livestock and poultry (113). Not all states have facilities for disease diagnosis; some may offer only partial services. Producers in many states routinely send material out of state for diagnostic services (113). However, the difficulty of properly shipping diseased organisms in some cases may preclude use of such services. Disease diagnosis is usually most effective with live organisms or organisms that have just died. Improper methods of preservation or long time delays until samples reach laboratories may make it difficult to identify the disease. Therefore, on-site diagnostic services may be the most useful but also are the most difficult to provide.

In addition to diagnostic and laboratory services, vaccinations could facilitate aquatic health management. Although numerous vaccines are marketed, the majority are limited as to their applications. Of the 15 products licensed with the U.S. Department of Agriculture, 12 are specifically used for salmonid production, one can be used with catfish, and two are nonspecific and can be used with any finfish (71). Additionally, vaccines are often effective against the causative agent(s) of only one disease (or monovalent).

Vaccines are not widely used in the United States because they are costly, they are only available for a narrow range of cultured organisms and, they commonly provide protection against only one type of disease (89). The degree of protection they provide may be variable depending on environmental conditions at the time of administration (111). They also may be difficult to effectively administer to cultured organisms (89).

Vaccination, however, can be effective in bringing disease outbreaks under control. For example, in the 1980s, cold water vibriosis, a serious problem for Norwegian salmon farmers, largely was controlled by expanded use of vaccines for this disease (101). Moreover, there is evidence that vaccination can be a cost effective measure in limiting disease outbreaks. The cost of vaccinating salmonids against furunculosis in a Norwegian hatchery was estimated to be less than 10 percent of the cost of providing medication after an outbreak according to Leiv Aarflot, president of the Norwegian Association of Aquaculture Veterinarians (111). Similarly, vaccines may be effective at reducing losses due to outbreaks of viral diseases for which there are no treatments. As vaccines gain wider use in the industry other benefits also may appear including reduced damage to the environment from less use of potentially harmful chemicals and safer products due to diminished antibiotic use (101).

Issue: Availability of Approved Drugs

Most individuals involved in aquaculture development describe lack of approved drugs as a major problem for the industry. Currently four drugs are approved and for use in aquatic species (table 2-1 and box 2-1). Another 17 drugs have been given low regulatory priority (box 2-2 and table 2-2) if they are used as prescribed (71). Low regulatory priority substances fit the definition of a drug as stated in the Federal Food, Drug, and Cosmetic Act, but present few safety concerns if used as specified and thus are allowed for such use (44).

Drug approval, performed by the Food and Drug Administration, requires that potential drugs have been established scientifically as safe and effective by the drug sponsor. Data must illustrate that the drug will be consistently and uniformly efficacious; that it will not harm the recipient; that it is safe to consume products derived from the recipient of the drug; that it will not affect people administering the drug or handling the recipient; and that the drug will not have an adverse impact on the environment (141). Generating data to meet these requirements is time consuming and expensive.

It is further required that drugs be approved on a species by species basis for a specific application. A cautious, species by species approach to drug approval has been implemented because many factors influence drug uptake, metabolism, and elimination. Different species may exhibit large differences

BOX 2-2: FDA Comments on Low Regulatory Priority Drugs

Why are garlic, ice, and onion described as low regulatory priority drugs? This question is often asked by aquaculture producers and others when reading over the list of low regulatory priority drugs prepared by FDA. Gary Stefan, Chief, Industry Programs, Center for Veterinary Medicine (as quoted in the July 1994 issue of *The Aquaculture News*) makes the following statements regarding FDA's position on this matter:

> The [Low Regulatory Priority] list has for some time included certain seemingly innocuous substances, such as salt, ice, onion and garlic. [FDA] continue[s] to receive comments and questions as to why such substances are on the list.
>
> The short answer is that we were asked for regulatory determinations on these substances and we wanted to be responsive to the requests. The substances are technically 'drugs' under the Federal Food, Drug and Cosmetic Act when used as proposed. By adding the substances to the LRP list, however, we intended to indicate that we had no regulatory interest in them, and we hoped that would put the matter to rest.
>
> As you may know, the definition of a drug in the Federal Food, Drug, and Cosmetic Act (the Act) is very precise. To paraphrase, any article intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in man or other animals, and any article (other than food) intended to affect the structure or any function of the body of man or other animals, is a drug. The key phrase is "intended use." For example, ice, when used to reduce metabolic rate (a function of the body of fish), would meet the definition of a drug under the Act because of its intended use. The use of ice for the purpose, such as preventing spoilage, would not be considered a drug use.
>
> Due to the precise definition of the term "drug" in the Act, certain seemingly innocuous substances are defined as drugs for certain uses. [FDA] does not have the discretion to define such uses as non-drug uses. The fact that certain substances are common in nature or are found in the human diet does not preclude their being defined as drugs for their intended uses. However, we do have authority to exercise regulatory discretion where the intended use does not raise significant human food safety or other concern.

SOURCE: "FDA Updates, Clarifies Information On Drugs Used In Aquaculture," *Aquaculture News* 2(9):16, July 1994.

TABLE 2-2: Unapproved New Animal Drugs of Low Regulatory Priority

Common name	Permitted use

Acetic acid	Used as a dip at a concentration of 1,000 to 2,000 milligrams per liter (mg/L)for 1 to 10 minutes as a parasiticide for fish.
Calcium chloride	Used to increase water calcium concentration to ensure proper egg hardening. Dosages used would be those necessary to raise calcium concentration to 10-20 mg/L calcium carbonate. Also used to increase water hardness up to 150 mg/L to aid in maintenance of osmotic balance in fish by preventing electrolyte loss..
Calcium oxide	Used as an external protozoacide for fingerling to adult fish at a concentration of 2,000 mg/L for 5 seconds.
Carbon dioxide gas	Used for anesthetic purposes in cold, cool, and warmwater fish.
Fuller's earth	Used to reduce the adhesiveness of fish eggs in order to improve hatchability.
Garlic (whole)	Used for control of helminth and sea lice infestations in marine salmonids at all life stages
Hydrogen peroxide	Used at 250-500 mg/L to control fungi on all species and at all life stages of fish, including eggs.
Ice	Used to reduce metabolic rate of fish during transport.
Magnesium sulfate (Epsom salts)	Used to treat external monogenetic trematode infestations and external crustacean infestations in fish at all life stages. Used in freshwater species. Fish are immersed in a solution of 30,000 mg/L magnesium sulfate and 7,000 mg/L sodium chloride for 5 to 10 minutes.
Onion (whole)	Used to treat external crustacean parasites and to deter sea lice from infesting external surface of fish at all life stages.
Papain	Used as a 0.2 percent solution in removing the gelatinous matrix of fish egg masses in order to improve hatchability and decrease the incidence of disease.
Potassium chloride	Used as an aid in osmoregulation to relieve stress and prevent shock. Dosages used would be those necessary to increase chloride ion concentration to 10-2,000 mg/L.
Providone iodine compounds	Used as a fish egg disinfectant at rates of 50 mg/L for 30 minutes during water hardening and 100 mg/L solution for 10 minutes after water hardening.
Sodium chloride (salt)	Used as a 0.5-1% solution for an indefinite period as an osmoregulatory aid for relief of stress and prevention of shock. Used as a 3 percent solution for 10-30 minutes as a parasiticide.
Sodium sulfite	Used as a 15 percent solution for 5 to 8 minutes to treat eggs in order to improve hatchability.
Thiamine hydrochloride	Used to prevent or treat thiamine deficiency in salmonids.
Urea and tannic acid	Used to denature the adhesive component of fish eggs at concentrations of 15 g urea and 20 g NaC1/5 L of water for about 6 minutes, followed by a separate solution of 0.75 g tannic acid/5 L of water for an additional 6 minutes. These amounts will treat approximately 400,000 eggs.

NOTE: FDA is unlikely to object at present to the use of these low regulatory priority substances if the following conditions are met:

1. The drugs are used for the prescribed indications, including species and life stage where specified.
2. The drugs are used at the prescribed dosages.
3. The drugs are used according to good management practices.
4. The product is of an appropriate grade for use in food animals.
5. An adverse effect on the environment is unlikely.

FDA's enforcement position on the use of these substances should be considered neither an approval nor an affirmation of their safety and effectiveness. Based on information available in the future, FDA may take a different position on their use.

Classification of substances as new animal drugs of low regulatory priority does not exempt facilities from complying with other federal, state, and local environmental requirements. For example, facilities using these substances would still be required to comply with National Pollutant Discharge Elimination System requirements.

SOURCE: Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production, in cooperation with the Extension Service, *Guide to Drug, Vaccine, and Pesticide Use in Aquaculture*, (Washington, DC: U.S. Department of Agriculture, 1994).

in processing drugs. For example, catfish treated with oxytetracycline, an approved antibiotic, reduce tissue concentrations of this chemical to acceptable levels within two days (at 27°C or 81°F), while chinook salmon require 30 days to reach the same tolerance level (at 8 to 10°C or 46 to 50°F) (5,110). Moreover, the same species may eliminate substances more slowly if the drug is administered at less than optimal temperatures (11).

The distribution of a drug in body tissues can also be important and may vary from species to species. Drug residues may be higher in internal organs or the skin than in muscle. In some species, such as catfish, this is of little concern because the skin typically is not consumed. In many salmonids, however, the skin may be eaten regularly and, if drug residues are retained at high concentrations in the skin, may pose health concerns to the consumer (110). Further studies of drug distribution in the tissues are needed as well as research on the metabolism of drugs.

Thorough research for drug approval also is required to ensure protection of the environment. Studies have found that antibiotics released into unconfined environments may alter the ecosystem. In some cases, antibiotics released into the water with feeds have adversely affected benthic organisms. In other instances antibiotics have been found in wild organisms in the immediate vicinity of fish farms that were using antibiotics in fish feed (36). For example, in a study conducted in Norway, wild fish caught in the vicinity of a fish farm immediately after drug treatment of the cultured fish contained concentrations of the drug oxytetracycline at levels many times higher than allowed by Norwegian law (84). Cooking the fish for 15 minutes did not reduce the drug residues present in the fish (84). Antibiotic resistant microbes also have been found where antibiotics have been widely used in aquaculture (36,123). There is a danger that human pathogens present in marine environments could become antibiotic resistant and thus adversely affect human health (90). Microbial surveys of aquatic environments near fish farms show that there are approximately 20 groups of microbes, potentially pathogenic to humans, commonly found in these areas (82,90).

Antibiotics or their metabolites are released into the water in feed in feces. High levels of drugs may enter the environment for several reasons. First, antibiotics may not be absorbed well in the gut of the animal requiring higher concentrations of these substances in the food. Oxytetracycline and other antibiotics for example are administered to fish in doses that are five to 10 times higher than doses used for humans (84). Second, sick animals have reduced appetites and generally do not consume the same quantities of food that healthy fish might normally consume (62). Excess food, therefore, may filter out of the cage and end up in the sediments. Once in the sediments, these chemicals may rapidly degrade or, depending on environmental conditions, may persist at low levels for extended periods (for at least one year) of time (123,150). In one experiment conducted in Norway, it took 142 days for initial oxytetracycline levels in the sediments below a net pen to degrade by one half (123).

Introduction of antibiotics into the environment can alter the dynamics of microbial populations as well as affect organisms higher in the food chain (84). In some cases, detrimental effects on fish growth and development have been observed when antibiotic concentrations in the water reached high levels (84). Additionally, chemicals that are toxic or that degrade slowly may build up to high concentrations in the sediments and have detrimental effects on bottom-dwelling organisms.[4]

The main obstacle to obtaining additional approved drugs is the cost of generating necessary data used to prove that the drug is

[4] To date most incidents of environmental impairment caused by use of antibiotics have taken place in situations where antibiotics were used prophylactically. Current regulations and the cost of administering antibiotics restrict this type of antibiotic use in the United States (135).

both effective and safe. Moreover, because this process must be repeated for each species and each disease, only a few drugs are approved and they are only permitted for use in a small number of species. Estimates for obtaining approval for a new animal drug to be used in food fish range from $3.5 million to $20 million dollars (43). Private industry is reluctant to invest these sums due to the market potential for aquaculture drugs in the United States. Federal and state agencies are trying to address this situation by investigating the concept of crop grouping, by conducting research under joint federal-state partnerships, and by allowing some extra-label use of approved drugs (e.g., use in other species).

Crop grouping has been proposed to hasten the development of data required for New Animal Drug Approval. Normally, a drug must be shown to be effective for each species and its disease condition; any other use is illegal. Obtaining separate approvals for each situation is costly (70). Crop grouping allows data obtained for a representative species of a group of species to be used to approve the drug for all members of that group. Species might be grouped according to genetic similarities (e.g., rainbow trout might represent salmonids), or environmental characteristics such as salinity requirements or water temperature (e.g., warm-water fish, cool-water fish, or cold-water fish). Studies showing that the selected groups of organisms metabolize various classes of drugs in a similar fashion will be needed (70).

The National Research Support Project for the Minor Use Animal Drug Program (NRSP-7) is also a mechanism for making additional drugs available to producers. The NRSP-7 program (formerly called the IR-4 program) provides funding for research needed to obtain clearance for animal drugs for minor and specialty crops (91). All cultured aquatic species are considered minor or specialty crops. Since 1990, 30 percent of NRSP-7 funds (totaling $664,500 from 1990 to 1994) have been used for research on drugs for use in aquaculture. Critics of the NRSP-7 program claim that it is not funded at a high enough level to generate the data necessary to gain drug approvals (43).

Recent legislation (Public Law 103-396) addressing extra-label use of drugs, amends the Federal Food, Drug, and Cosmetic Act to permit a veterinarian to order "1) a new animal drug, approved for one use to be used for a different purpose other than a use in or on animal feed; and 2) a new drug approved for human use to be used in animals." Some believe this legislation could help the aquaculture industry gain access to more drugs to aid disease control (132). Conversely, others believe this law may have minimal effect on the industry because of a shortage of suitably trained veterinarians in some areas and because of its potential to restrict FDA's current policy of allowing some extra-label use of medicated feeds (45,132).

Issue: Coordination of Regulation

At least six federal agencies and numerous state agencies are involved in aquatic health management issues (tables 2-3 and 2-4). Many involved in the aquaculture industry believe that the distribution of regulations among so many agencies is confusing. For example, pesticides for aquatic use are governed by the EPA; antibiotics, other drugs, animal feeds, and feed additives are regulated by the FDA (45), and the licensing of vaccines is the responsibility of APHIS. States may have their own laws regulating transport of cultured products across state boundaries as well as other aquatic health management regulations.

In addition, federal and state authorities may be split for some regulatory activities. For example, the EPA may cede authority to issue effluent emission permits to a state agency. The state agency is responsible for making sure that basic federal requirements are met along with any additional state regulations (121). State water-quality programs may help to determine where shellfish can be safely grown (120). Likewise, many states have enacted their own versions of the Food, Drug and Cosmetic Act, making it illegal to transport contaminated or adulterated food within state boundaries (121).

Seafood-safety inspections also may be carried out at the state level, especially in states such as Florida that produce large quantities of seafood (121).

States also may be acceded some authority to administer the Lacey Act. The Lacey Act attempts to restrict the movement of potential pathogens into the United States and into watersheds where the pathogen is not currently found. The Lacey Act attempts to accomplish this goal by formulating a list of "injurious" species or groups of fish, wildlife, and fish pathogens that states are prohibited from importing (139). Oversight of this legislation is the responsibility of the U.S. Department of the Interior, Fish and Wildlife Service. States, however, may develop prohibited species lists that suit their own unique needs. Many states require aquaculture products to be certified as disease free for specific pathogens before they can cross state lines (143). This state by state approach has resulted in a patchwork of regulation. According to many aquaculture producers, the lack of uniformity in Lacey Act requirements established by each state has impeded interstate commerce of aquaculture products.

Some attempts have been made to improve coordination among agencies regulating aquatic health management. The Joint Subcommittee on Aquaculture (JSA) was created to act as a facilitator among all the agencies involved in aquaculture and has been active in aquatic health issues. JSA, has, for example, established a list of priority drugs needed by the aquaculture industry; published information on the use of drugs, vaccines and pesticides in aquaculture; and worked on quality assurance issues.

Examples of state-federal cooperative efforts include the Sea Grant College Program which supports research, education and extension activities funded by the state and the National Oceanic and Atmospheric Administration (NOAA); and the Cooperative State Research Education and Extension Service of USDA, which awards grants to state experimental stations, land-grant colleges, and colleges of veterinary medicine. Recently, 39 states have joined the federal government in an $8 million study of eight drugs determined to be priority needs for disease treatment in state and federal hatcheries as well as in aquaculture systems (148).

TECHNOLOGIES IN AQUATIC HEALTH MANAGEMENT: PREVENTION AND TREATMENT

Disease prevention is accomplished by good husbandry practices such as maintaining optimum environmental conditions, good sanitation, and proper nutrition; by breeding disease-resistant varieties and using certified disease-free stocks; and by chemical prophylaxis, vaccination, and disease diagnosis (127).

Maintaining Proper Environmental Conditions

Poor water quality is a common factor in disease outbreaks. Cultured species have variable tolerance ranges for such parameters as dissolved oxygen, ammonia concentration, and water temperature. Stress and eventually death may occur when these parameters fall outside an optimum range. Proper conditions may be easier to maintain in closed systems than in open pond systems. Continuous monitoring of water quality parameters is essential for maintaining optimum environmental conditions (127).

Various technologies exist for monitoring and upgrading water quality. For example, if dissolved oxygen falls to low levels in a pond, emergency aeration using mechanical aerators will help increase the concentration of dissolved oxygen. Likewise, biofilters can be used to lower ammonia levels in the water. In some systems, such as net pens, the choice of a site can also help to ensure proper water quality: a site where the water exchange rate is high, with specific bottom characteristics or a certain depth and oxygen-rich waters will reduce problems (58). Similarly, choosing a site with the proper

salinity characteristics may diminish disease problems in cultured oysters as some pathogens have narrow salinity tolerances (127).

Sanitation

Disease outbreaks can be reduced by using good sanitation practices. For example, workers should wash all gear as well as their bodies and clothes thoroughly before and after handling diseased organisms. Nets used to retrieve organisms should be dipped in a disinfectant solution before each new use, including use in a neighboring pond or tank (134). Disinfecting ponds by draining and adding lime also helps reduce disease problems from organisms that may survive in pond bottoms (14).

Nutrition

Organisms receiving proper nutrition are less likely to become ill. Lack of specific nutrients, such as vitamins or minerals, may lead to disease. For example, insufficient vitamin E in the diet may cause reduced growth and survival, anemia and exophthalmia (bulging eyes) (134). Paradoxically, excess levels of vitamins also can cause illness. Vitamin E given in excess causes poor growth, toxic liver reaction, or potentially death (134). Lack of information about a cultured organism's nutritional requirements is often a serious constraint to improved disease management in aquaculture (80).

Disease-Resistant Stocks

Breeding and using disease-resistant organisms also may be a mechanism that could help prevent loss. In one study, brown trout (*Salmo trutta*) were selected for resistance to furunculosis--a common disease that affects salmonids. After one generation, offspring from selected parents and control parents were exposed to *Aeromonas salmonicida*, the causative agent of furunculosis. Mortality due to furunculosis six months after hatching was 2 and 48 percent, respectively, in the selected versus the control group (21). Enhanced disease resistance may be an inadvertent feature of other rearing techniques. For example, triploid American oysters (*Crassostrea virginica*) grow faster than normal oysters and thus are capable of reaching market size before being killed by the parasite *Perkinsus marinus* (7).

Certified Disease-Free Stocks

Diseases may be prevented by using eggs, embryos, juveniles or broodstock that have been certified as disease free. Many states now have programs to certify that various organisms are disease-free (89). Similarly, FWS and USDA's Animal and Plant Health Inspection Service (APHIS) provide some diagnostic assistance and export certification for nonmammalian aquatic and aquacultured animals, including gametes and embryos (80).

USDA and a consortium of four other organizations (the Oceanic Institute in Hawaii, the Waddell Mariculture Center in South Carolina, the Gulf Coast Research Laboratory in Mississippi, and the University of Arizona Department of Veterinary Science) formed a program to supply specific pathogen free (SPF) broodstock of the Pacific shrimp (*Penaeus vannamei*) to several commercial hatcheries. Results from commercial pond trials have shown that SPF shrimp exhibit improved growth, survival, feed conversion ratios, and higher production rates than non-SPF shrimp in some areas (120,152).

Chemical Prophylaxis

Chemical treatment to reduce potential pathogens is another technique for reducing disease. For example, treating salmonid eggs with hydrogen peroxide or a formalin solution can remove potentially harmful fungi. Similarly, clams may be dipped in sodium hypochlorite solution to reduce surface-coating bacteria (127).

Vaccines

Significant progress has been made in recent years in the development of vaccines to prevent a wide range of diseases in finfish, shellfish, and crustaceans (31,67). Vaccines can be administered in several ways including by injection, immersion, spraying on the skin of the

organism, and orally (134). Currently, 15 vaccines are registered in the United States, most of which are for use with salmonids (71). Routine use of vaccines has reduced the frequency of disease outbreaks and consequently, the use of antibiotics (31).

Disease Diagnosis

Early and accurate diagnosis also is important for disease control. The first step in disease diagnosis involves constant monitoring of cultured organisms especially after stress-inducing events such as temperature fluctuations, or capture and transport. Variations in behavior, reluctance to eat, discoloration of the skin and the presence of lesions can indicate potential disease problems (134). In addition to constant observation of cultured organisms, tools such as microbiological testing and gene probes can help identify the presence of disease agents (31,74).

Managerial Methods to Treat Disease

Management interventions are generally the first steps taken in treating a disease outbreak. If disease is present, immediate steps should be taken to reduce stress to the organisms and to limit the spread of disease by isolating the sick and removing the dead organisms (134). Restoring optimal environmental conditions could help to reduce the impact of the outbreak. In some cases environmental parameters can be directly altered to reduce parasite levels. For example, the parasite *Ichthyophthirius multifiliis*, which affects freshwater cultured fish, can be controlled by increasing or reducing water temperature or by increasing salinity (134). Biological control methods also may be possible (box 2-3).

Chemical Methods to Treat Disease

Three types of legal chemical disease treatments exist in the United States: two are regulated by the FDA -- approved New Animal Drugs and unapproved New Animal Drugs of Low Regulatory Priority (tables 2-1 and 2-2). The third is EPA-registered pesticides. Drugs can be administered to cultured organisms in several ways: added directly to the water, added to the feed, injected into the organism, or the organisms can be dipped in a solution of the chemical (134).

All legal chemical treatments have strict requirements governing their use. For example, one approved drug[5] can be used only on catfish to treat enteric septicemia or on salmonids to control furunculosis. For any chemical treatment, only specified concentrations may be used, adequate withdrawal times must be adhered to, and tissue residues must be below established levels (71).

CONCLUDING REMARKS

The role of the federal government in aquatic health management is complex. Many agencies have programs or regulations concerning aquatic health management (tables 2-3 and 2-4). The Joint Subcommittee on Aquaculture (JSA) will most likely continue to play an important role in coordinating agency efforts to promote improved aquatic health management and protect consumer interests.

The private sector is playing an increasingly important role in aquatic health management. Frequently, there is collaboration between federal and state agencies and private groups in health related matters. For example, a recent publication, the "Guide to Drug, Vaccine, and Pesticide Use in Aquaculture" prepared by the JSA (August 1994), was funded by a consortium of federal agencies and industry groups (71). Industry groups such as the Catfish Farmers of America (CFA) and the U.S. Trout Farmers Association (USTFA) also have been active in creating quality assurance programs for their members to follow (87).

[5] Sulfadimethoxine and ormetoprim, tradename Romet 30.

BOX 2-3: Biological Control of Sea Lice

Sea lice (various species from the genera *Argulus*, *Caligus*, *Ergasilus*, *Lepeophtheirus* and *Pseudocaligus*) (119) are external parasites that attach to the skin of fish and feed on underlying tissues and blood (125). Sea lice parasites can be transmitted through the water column, from host to host, or from wild fish to cultured fish (119). Skin lesions, reduced growth, and mortality caused by the sea lice reduce the marketability of the fish (125). Infections in wild fish are relatively rare and characterized by small numbers of parasites; however, high densities of fish on fish farms encourage the spread of these parasites (125). Once established in a population, parasite numbers increase and may eventually reach epidemic proportions after several years.

Treatment of sea lice infections has traditionally relied on the use of chemicals, especially dichlorvos, an organophosporous pesticide. Net pens are treated by surrounding the pen with a tarp and then adding the chemical to the water (119). At the end of the treatment period, the tarp is removed and pesticide is released into the environment. Frequent treatments are required (every three to four weeks) because the pesticide is only effective against the adult stages of the parasite and does not affect larval stages in the water column. Additionally, the parasite can be re-transmitted to cultured fish from wild fish (106,119).

Frequent use of chemicals to treat sea lice infestations can cause several additional problems. First, applying chemicals is expensive, time consuming, and labor intensive (101,106). Second, widespread use of chemicals may damage the environment, stress the fish, and cause health problems in cultured and wild fish (66,101,119). Third, treatment efficacy is variable depending on temperature of the water and concentration of the chemical within the water (119). Fourth, parasites have started to show resistance to the main chemical dichlorvos, so increasing amounts of the chemical will be needed to contain the infections. Application levels of dichlorvos, however, can only be increased slightly before toxic effects are seen in the cultured fish (66,119).

To reduce chemical use in the treatment of sea lice tests have been made of biological control agents. For example, fish such as the gold sinny wrasse (*Ctenolabrus rupestris*) will remove and consume external parasites from other fish. Experiments have shown that adding these fish to salmon net pens decreases the need for chemical treatments to reduce sea lice infestation. In one trial, 600 wrasse were added to a sea cage containing 26,000 salmon. The salmon growing in this cage did not require chemical treatment but the control group that contained no wrasse had to be treated several times during the course of the study to reduce sea lice infection (106). Additional experiments evaluating control of sea lice with the gold sinny wrasse are currently taking place in Scotland and Norway (106). Further evaluation of this technique and other biological pest control methods may be able to reduce the use of chemical treatment for sea lice.

SOURCE: Office of Technology Assessment, 1995.

Research on antibiotics also may be performed on a collaborative basis due to the high cost associated with gaining data necessary for drug approval. In one case, the U.S. Fish and Wildlife Service and Abbott Labs have performed joint studies on the metabolism and pharmacokinetics of sarafloxacin, a potential drug candidate for aquaculture,[6] as well as methods to detect sarafloxacin residues in tissues of fish (46,47).

Similarly, researchers from the U.S. Department of Agriculture, Agricultural Research Service (ARS) have developed a test that identifies whether catfish have been exposed to the pathogen, *Edwardsiella ictaluri*, the cause of potentially fatal enteric septicemia in catfish. DiagXotics, Inc., of Wilton Connecticut, a producer of other aquaculture related diagnostic tools, has obtained a license from ARS to produce and market the diagnostic test kit, which is expected to be available in 1996 (62). Private industry has also produced aquatic health management products independently. For example, vaccines are manufactured by two private companies: BioMed, Inc. of Bellevue Washington and Aqua Health, LTD. of Canada. Together, they produce 15 different vaccines primarily for use with salmonids (71).

Private-sector involvement in producing vaccines and offering health related services

[6] As of June 23, 1995, Abbott Laboratories has discontinued development of sarafloxacin for aquaculture use in the U.S. (1).

will likely grow in the future. However, it is unlikely that private industry will invest the large sums of money necessary to generate data required for approval of a wide range of drugs. In many cases, the costs involved are too high and the potential profits too low to justify private-sector initiative. Therefore, collaborative efforts between federal and state agencies, and private industry will continue to be important. Other possibilities also exist, for example, if crop grouping for drug approval is determined to be viable or the FDA agrees to permit drug uses for non-food organisms or classify certain life-stages as non-food, then more drugs may become available for use in aquaculture.

Regardless of whether more drugs gain approval, public acceptance of aquaculture products will derive from the perceived quality and safety of the products. If consumers perceive that drugs are widely used in the industry, then they may be reluctant to purchase these products. To avoid problems of this nature, research could focus on such preventative measures as vaccination; production of genetically improved, high health broodstock, and seedstock for commercially important species; and establishing Best Management Practices (BMP) for reducing disease.

Formulating BMPs requires considerable data on impacts of diseases on aquaculture, especially among marine systems and less prominent animals and plants. To address the current dearth of information, it may be possible to expand present USDA data collection systems to address entire life cycles of cultured animals and plants. Using existing programs such as cooperative extension services to collect data within each state for all cultured species could help to fill information gaps. This might help to determine actual economic losses incurred by aquaculturists, provide data to support requests for federal help, and aid in identification of unrecognized disease problems. If this type of data could be compiled and disseminated it also would be useful for formulating management strategies to reduce mortality due to disease. However, much of these data would be difficult to obtain, especially for outdoor ponds, and likely would require additional funding for training extension workers (89).

Data also are needed to harmonize Lacey Act requirements. Regulations governing the movement of fish and wildlife to control the spread of disease organisms across state and international borders are promulgated by individual states resulting in a patchwork of often conflicting requirements. Congress could request that one federal agency, such as the Fish and Wildlife Service, establish guidelines for uniform health certification procedures among all states and with foreign countries. Attempts could be made to map the disease status of facilities, watersheds, or regions to assist in a uniform program to prevent the spread of disease to new areas (80). Stronger cooperation among states with more federal intervention may be necessary to eliminate the disparity and confusion that exists as an obstacle to interstate trade. A strong, uniform program in the United States may facilitate reasonable agreements with other countries and international trade.

3
Biotechnology

Advances in biotechnology have made the modern aquaculture industry possible. In this report, biotechnology includes traditional technologies, such as hormonally induced spawning, as well as newer techniques including gene transfer and frozen storage of genetic material (cryopreservation) (see table 3-1 and box 3-1).

Early techniques in aquaculture focused simply on collection of organisms, or fertilized eggs from the wild, and transfer to ponds or enclosures of estuarine embay-ments. Production relied on the natural reproduction cycle. Successful fertilization of eggs and spawning of organisms in artificial environments permitted greater con-trol over reproduction. Increased production, and thus large-scale aquaculture, became possible with the discovery of hormonally-induced spawning techniques. Selective breeding and the year-round production of juveniles (and consequently, products), further advanced the industry (30,86).

CONGRESSIONAL INTEREST

Increasing use of biotechnologies in aquaculture is of concern to Congress because federal oversight of some aquatic genetically modified organisms (GMOs) is now fragmented among several federal agencies (table 3-2), while other aquatic GMOs receive no federal oversight. Although several federal agencies have developed guidelines or promulgated regulations governing use of GMOs, some congressional members, scientists and others believe that new legislation, specifically addressing the use and release of aquatic GMOs, may be needed to minimize potential adverse impacts on the environment and human health and safety (74). Congressional interest also focuses on the need for establishing research and funding priorities. Some congressional members as well as scientists and others believe that research

BOX 3-1: Biotechnology Definitions

OTA uses the adjectives **genetically engineered** and **transgenic** to describe plants, animals, and microorganisms modified by the insertion of genes using genetic engineering techniques. **Transgenes** are the genes which are inserted into an organism.

Genetic engineering refers to recently developed techniques through which genes can be isolated in a laboratory, manipulated, and then inserted stably into another organism. Gene insertion can be accomplished mechanically, chemically, or by using biological vectors such as viruses.

Genetically modified organisms have been deliberately modified by the introduction or manipulation of genetic material in their genomes. They include not only organisms modified by genetic engineering, but also those modified by other techniques such as chemical mutagenesis, and manipulation of sets of chromosomes.

Biotechnology refers to the techniques used to make products and extract services from living organisms and their components. A broad interpretation of biotechnology includes all biological technologies important to the successful development of aquaculture, i.e., both traditional technologies such as hormonally induced spawning and selective breeding, as well as newer techniques such as gene transfer and frozen storage of genetic material (cryopreservation). An alternative definition of biotechnology reserves this term for only the newer techniques.

SOURCE: Office of Technology Assessment, U.S. Congress, *Harmful Non-Indigenous Species in the United States*, OTA-F-565 (Washington, DC: U.S. Government Printing Office, September 1993).

TABLE 3-1: Biotechnology Applications and Methodologies

Technology	Description	Species	Potential benefits	Potential risks
Reproduction				
Broodstock maturation	Induced spawning by environmental or hormonal manipulation	Crustaceans, Finfish, Molluscs	Enables year-round production	May require use of unapproved drugs
Induced or synchronized spawning	Hormonal induction of gamete formation	Crustaceans, Finfish, Molluscs	Increases range of species that can be produced	May require use of unapproved drugs
Hybridization between species	Crossbreeding of closely related species	All species	Allows production of offspring with unique characteristicsor sterile organisms	Escapement may cause dilution in wild gene pools
Protoplast fusion	Fusion of plant cells from different species	Aquatic plants	Allows production of offspring with unique characteristics including faster growing varieties	Risks undetermined
Growth and development				
Incubation & larval rearing	Identification of nutritional needs and physical parameters for optimal incubation	All species	Raises productivity, increases growth, and improves survival rates	May pose few risks
Development and metamorphosis	Hastening physical transformation by hormonal or environmental manipulation	Crustaceans, Finfish, Molluscs	Facilitates salt water tolerance in salmon	May require use of unapproved drugs
Growth acceleration & improved food conversion	Administration of hormones	Finfish, Molluscs	Increases growth rate and reduces production time	May require use of unapproved drugs
Sex control/monosex populations				
Direct feminization/ masculinization	Sex change of organism by exposure to estrogen or testosterone derivatives	Finfish	Limits reproduction; creates monosex populations quickly and easily	May require use of unapproved drugs; may not be 100% effective

TABLE 3-1: Biotechnology Applications and Methodologies (cont'd.)

Technology	Description	Species	Potential benefits	Potential risks
Chromosome set manipulation				
Androgenesis Gynogenesis	Production of organisms that contain genetic material from only father or only mother	Finfish	Facilitates production of monosex sperm; enables recovery of organisms from cryopreserved sperm	Escapement may cause inbreeding or gender imbalances in wild receiving populations
Triploidy	Production of organisms with three sets of chromo-somes	Finfish, Molluscs	Retards sexual development, causes sterility; may reduce genetic impact on wild organisms	May cause competition with wild organisms; may not be 100 percent effective[a]
Tetraploidy	Production of organisms with four sets of chromo-somes	Finfish, Molluscs	Facilitates production of triploid offspring	May pose few risks due to low survival in wild
Genetics				
Marker-assisted selection	Introduction of DNA markers into cultured organism	All species	Facilitates traditional selection	May pose few risks
Stock identification with DNA technology	Identification of species and lineage using DNA sequences	All species	Identifies hybrids; separates close relatives for breeding purposes	May pose few risks
Gene banks and sperm cryopreserva-tion	Indefinite storage of genetic material in liquid nitrogen	All species	Allows gene banking for conservation and breeding	May reduce impetus to restore or protect environment
Gene transfer				
Antifreeze gene Nutritional enhancement Disease resistance Growth enhancement	Introduction of a gene that is coded for a specific trait into a new organism	Finfish	Allows expansion of aquaculture to new environments; creates organisms with new traits; speeds up production	May pose ecological, genetic, health, safety and social risks

TABLE 3-1: Biotechnology Applications and Methodologies (cont'd.)

Technology	Description	Species	Potential benefits	Potential risks
Health				
Stress assessment	Investigation of methods to detect and reduce stress	Finfish	Lowers mortality and may increase profits	May pose few risks
Diagnostic tests	Use of sensitive and rapid tests to identify diseases	All species	May increase production and profits	May pose few risks
Vaccine development	Development of vaccines to provide protection against various diseases	Crustaceans, Finfish	May increase production and profits	May pose few risks
Antibiotic development	Development of antibiotics to treat disease outbreaks	Crustaceans, Finfish, Molluscs	May reduce loss to disease	Incurs health and safety and ecological risks
Pharmaceutical delivery mechanisms	Development of methods to deliver pharmaceu-ticals; may be oral, by injection, by immersion, or via implantation	Finfish	May improve efficacy of treatment	May pose few risks
Nutrition	Finding alternative sources of protein and altering diets of cultured organisms	Crustaceans, Finfish	Reduces need for fish protein in diet; may make products healthier for consumers	May pose few risks

NOTE: Amphibians and Reptiles have been excluded from the table

[a] An experiment with transplanted triploid Pacific oysters (*Crassostrea gigas*) was terminated when it was discovered that some of the oysters had reverted to diploid status (see box 3-6) (12).

SOURCES: Office of Technology Assessment, 1995; E.M. Donaldson, Fisheries and Oceans Canada, West Vancouver, British Columbia, "Biotechnology In Aquaculture," unpublished report prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, November 1994; and A.R. Kapuscinski and E.M. Hallerman, Sea Grant College Program, University of Minnesota, St. Paul, MN, Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA, "Benefits, Environmental Risks, Social Concerns, and Policy Implications of Biotechnology in Aquaculture," unpublished contractor report prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, October 1994.

TABLE 3-2: Federal Policies and Regulations Related to the Environmental Release of Aquatic Genetically-Modified Organisms Since 1984

Office of Science and Technology Policy	
1992	Exercise of Federal Oversight Within Scope of Statutory Authority: Planned Introductions of Biotechnology Products into the Environment, 57 *Federal Register* (FR) 6753 (*Policy Statement*)
1990	Principles for Federal Oversight of Biotechnology: Planned Introduction into the Environment of Organisms with Modified Hereditary Traits, 55 FR 31118 (*Proposed Policy*)
1986	Coordinated Framework for Regulation of Biotechnology, 51 FR 23302 (*Policy Statement and Request for Public Comment*)
1985	Coordinated Framework for the Regulation of Biotechnology; Establishment of the Biotechnology Science Coordinating Committee, 50 FR 47174
1984	Proposal for a Coordinated Framework for Regulation of Biotechnology, 49 FR 50856 (*Proposed Policy*)
The President's Council on Competitiveness	
1991	Report on National Biotechnology Policy (*Policy Statement and Recommendations for Implementation*)
U.S. Department of Agriculture, Animal and Plant Health Inspection Service	
1993	Genetically Engineered Organisms and Products; Notification Procedures for the Introduction of Certain Regulated Articles; and Petition for Nonregulated Status, 58 FR 17044 (*Final Rule*)
1992	Genetically Engineered Organisms and Products; Notification Procedures for the Introduction of Certain Regulated Articles; and Petition for Nonregulated Status, 57 FR 53036 (*Proposed Rule*)
1987	Introduction of Organisms and Products Altered or Produced Through Genetic Engineering Which Are Plant Pests or Which There Is Reason to Believe Are Plant Pests, 7 CFR 340 (*Final Rule*)
1986	Final Policy Statement for Research and Regulation of Biotechnology Processes and Products, 51 FR 23336 (*Final Policy Statement*)
1986	Plant Pests: Introduction of Organism and Products Altered or Produced Through Genetic Engineering Which are Plant Pests or Which There is Reason to Believe are Plant Pests, 51 FR 23352 (*Proposed Rule and Notice of Public Hearings*)
U.S. Department of Agriculture, Office of Agricultural Biotechnology	
1995	Performance Standards for Safely Conducting Research With Genetically Modified Fish and Shellfish (*Voluntary Performance Standards*)
1990	Proposed USDA Guidelines for Research Involving the Planned Introduction into the Environment of Organisms with Deliberately Modified Hereditary Traits, 56 FR 4134 (*Proposed Voluntary Guidelines*)
1986	Advanced Notice of Proposed USDA Guidelines for Biotechnology Research, 51 FR 13367 (*Notice for Public Comment*)
U.S. Environmental Protection Agency	
1994	Microbial Products of Biotechnology Proposed Regulations Under TSCA, 59 FR 45528 (*Proposed Rule*)
1993	Microbial Pesticides; Experimental Use Permits and Notifications, 58 FR 5878 (*Proposed Rule*)
1989	Biotechnology: Request for Comment on Regulatory Approach, 54 FR 7027 (*Notice*)
1989	Microbial Pesticides; Request for Comment on Regulatory Approach, 54 FR 7026 (*Notice*)
1986	Statement of Policy: Microbial Products Subject to the Federal Insecticide, Fungicide, and Rodenticide Act and the Toxic Substances Control Act (TSCA), 51 FR 23313 (*Policy Statement*)

SOURCES: Office of Technology Assessment, U.S. Congress, *Harmful Non-Indigenous Species in the United States*, OTA-F-565 (Washington, DC: U.S. Government Printing Office, September 1993); U.S. Department of Agriculture, "1995 Farm Bill--Guidance of the Administration" (Washington, DC, 1995a).

priorities for biotechnologies used in aquaculture should include development of modern technologies as well as applications of traditional methods; and that more emphasis is needed on understanding the consequences of releasing GMOs into the environment,

including possible threats to public health or safety (74,139).

ISSUE IDENTIFICATION

Issue: Federal Policy for Biotechnology in Aquaculture

Federal biotechnology policies in the United States are described in the Coordinated Framework for the Regulation of Biotechnology (102,103). Policies described in the Coordinated Framework are based on existing federal legislation to regulate the development and commercialization of GMOs. Existing legislation includes the National Environmental Policy Act (NEPA) (administered by the Environmental Protection Agency) as well as legislation under the jurisdiction of the Food and Drug Administration (FDA) and the U.S. Department of Agriculture (USDA) (table 3-2).

The Office of Science and Technology Policy published the "Scope" document in 1992, a supplement to the Coordinated Framework. The Scope document did not change existing regulations but had two prominent features that provided a framework for allowing agencies to exercise discretion in explaining their policies under existing law (25). First, this document declared that regulatory oversight was to be based on characteristics of the organism itself, rather than the process that modified it. Second, regulation of the products of biotechnology would be based on the risks the organism posed to human health or to the environment (74).

The two criteria set forth by the scope document created some controversy. For example, defining a modified organism by its characteristics is difficult. An organism's phenotype or outward appearance is a product of its genetic makeup plus environmental influences, and thus highly variable. Given different environmental influences the phenotype can change. Therefore, each use of a modified organism would have to be evaluated on a case by case basis, which might be impractical when large numbers are involved. Additionally, the uncertain nature of an environmental influence on an organism's phenotype may make it difficult to assess risks that modified organisms could pose in different habitats. Risk assessment and management is currently constrained by a dearth of information needed to assess the release of aquatic GMOs (74).

In recognition of the need to more clearly define how existing laws governed the release of GMOs, several agencies updated their current policies and issued new regulations or guidelines.[1] Publication of the coordinated framework could be considered the start of an ongoing process by which the federal government and agencies explain how biotechnology development and commercialization could be handled (25).

Despite changes in laws and regulations enacted, some believe that regulatory authority over aquatic GMOs may be incomplete. For example, National Institutes of Health (NIH) guidelines for research with recombinant DNA do not necessarily apply to aquatic GMOs and use of the NIH guidelines may be voluntary in certain circumstances[2] (74,95,96,97). In addition, it may be difficult to determine which agency has jurisdiction over the regulation of an aquatic GMO (box 3-2.). For example, APHIS regulates release of certain genetically modified plants and live animal vaccines and EPA regulates the release of some genetically modified microbes and has proposed legislation to regulate microbial products of biotechnology and plants containing pesticide genes (51,139).

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[1] For example, USDA's Animal and Plant Health Inspection Service (APHIS) promulgated new regulations in 1987 under the Federal Plant Pest Act and the Plant Quarantine Act and added amendments to these regulations in 1993 (74). FDA issued a policy statement clarifying its interpretation of the Federal Food, Drug and Cosmetic Act with respect to foods derived from new plant varieties and issued guidance for safety evaluation.

[2] Federal agencies or organizations that receive federal dollars or use federal resources are required to comply with NIH guidelines. Private sector activities without federal involvement are not required to comply with NIH guidelines but often do so voluntarily (25).

However, many genetically modified aquatic organisms do not clearly fall under the umbrella of any legislation when they are conducted by the private sector. Some have suggested the Lacey Act be invoked to regulate "unassigned" GMOs but this legislation delegates responsibility for oversight of releases of fish and game to the states. State legislation may not be as desirable because aquaculture products may be regulated more effectively under a federal framework that simplifies commerce among companies in different states, and state oversight may not adequately protect the environment because many states lack oversight programs for GMOs (51). Another alternative is for the FWS to become involved in limiting interstate transport of species designated as prohibited or injurious by a state (139). FWS already provides certification services to ensure that grass carp (*Ctenopharyngodon idella*) are triploid (139).

FDA also may have a role to play. The definition of a new animal drug (chapter 2) is broad enough to include the introduction of transgenes into an organism. If FDA declared that transgenes were new animal drugs then they would have the authority to regulate all stages of commercialization of transgenic organisms including the investi-gational or developmental stages prior to production. This approach may hinder commercial production of transgenic aquatic organisms because of the high costs associated with obtaining new animal drug approvals (25,68).

Anticipating further requests for releases, the USDA Office of Agricultural Biotechnology, through a working group under its Agricultural Biotechnology Research Advisory Committee (ABRAC), developed Performance Standards for Safely Conducting Research with Genetically Modified Finfish and Shellfish (2). The

BOX 3-2: Release and Confinement of Transgenic Fish

To date, only two federally-funded outdoor experiments with transgenic aquatic organisms have taken place in the United States. In both cases, the USDA Cooperative State Research, Education and Extension Service (CSREES)[a] requested the Agricultural Biotechnology Research Advisory Committee (ABRAC) to provide assistance in the environmental assessment. The first study, proposed for confined outdoor ponds by Auburn University's Agricultural Experiment Station, involved rearing a transgenic line of common carp (*Cyprinus carpio*) with a rainbow trout growth hormone gene (74).

Initially there was some confusion about which Federal agency claimed jurisdiction over the project and the appropriate Federal forum for review of the proposal's safety.[b] Eventually it was determined that the responsibility for oversight of the experiment lay with the agency partially funding the research, in this case CSREES (139). Under the National Environmental Policy Act (NEPA), an environmental assessment was conducted by CSREES and no significant environmental impact was found associated with the project. This finding was met with strong criticism and prompted the agency to conduct another assessment with help from ABRAC. The new assessment also concluded that the experiment would result in no significant impact to the environment but was contingent upon significant improvements to the outdoor facilities at Auburn University. Modifications included rearing fish in ponds at a higher elevation (to avoid the floodplain) and effluent filtration (139).

In 1992, Auburn University subsequently sought approval to use federal funds to conduct a similar study with transgenic channel catfish (*Ictalurus punctatus*) in newly constructed ponds above the 100-year flood plain and built with numerous barriers to escape including several barriers in effluent filtration (75). The study was approved after CSREES analyzed the data and determined that the experiment would have no significant impact. In both cases, the reviews were conducted without benefit of guidelines tailored to issues raised by aquatic GMOs, which led the ABRAC to develop guidelines (2,74).

[a] Formerly the Cooperative State Research Service (CSRS).
[b] When a regulatory agency has jurisdiction over an activity funded by another agency, normally the regulatory agency (sometimes in collaboration with the funding agency) conducts the environmental review consistent with NEPA (25).
SOURCE: Office of Technology Assessment, 1995.

Performance Standards are a focused step toward defining clear U.S. oversight policy on the development and use of genetically modified aquatic organisms. The Performance Standards are voluntary guidelines for assessing the environmental effects of proposed research with genetically modified fish and shellfish, excluding organisms modified solely by traditional breeding, and, when use of the standards leads to identification of specific risks, for selecting confinement measures (74). These guidelines establish a methodology for assessing which organisms present problems to wild organisms and natural ecosystems (boxes 3-3 and 3-4). The guidelines also provide risk management recommendations and recom-mend peer review of proposed projects and evaluation of the facilities used in the experiment (2).

Environmental reviews of the release of aquatic GMOs under federally-funded research programs are also carried out by funding agencies in accordance with their obligations under the National Environmental Policy Act (NEPA). NEPA requires all federal agencies to consider the environ-mental consequences of actions, including a decision to fund a particular research study. Although NEPA requires full consideration of environmental consequences, it does not preclude approval of actions even when they may have a significant impact (74).

The Food and Drug Administration (FDA) is one of the agencies with jurisdiction over products of biotechnology. FDA regulates new animal drugs under the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 360b). Drugs are defined in this Act as articles other than food intended for use in the diagnosis, treatment, or prevention of disease, or that affect the structure or function of the body of an animal. Although FDA policy in this area is still under development, the agency may find that introduction of transgenes[3] intended to affect the structure or function of an animal's body constitutes a new animal drug use. If FDA decides to take this approach, the agency would have the authority to approve commercialization of transgenic fin-fish or shellfish, provided that the transgenes (the "new animal drug") were determined to be safe for the animal and for persons eating foods derived from the animal (74,130). Under NEPA, FDA would also have to fully consider the environmental impacts of transgenic finfish and shellfish before they were approved by the agency (51).

BOX 3-3: Frequency of Escape from Aquaculture Facilities

What is the chance that organisms will escape from aquaculture facilities or be released into the environment as a result of aquaculture activities? This question is an important one to consider when assessing environmental risks. In the past, large numbers of organisms are thought to have escaped from aquaculture facilities, especially from ocean net pens used to raise finfish. For example, in 1993 the Canadian Department of Fisheries and Oceans reported that 4,500 farmed Atlantic salmon had been captured from the Pacific coast and that total estimated catch was probably closer to 10,000 farmed fish. Similarly, 32,000 fish reportedly escaped in 1994 from one aquaculture facility in British Columbia.

Fish aren't the only organisms that can escape or be released into the environment as a result of aquaculture activities. Pacific white shrimp (*Penaeus vannamei*) have been captured off the coast of South Carolina (139). Aquatic plants used in the aquarium trade, such as hydrilla and water hyacinth, were introduced into canals in Florida and have subsequently become plant pests (72,139). Likewise, potential establishment of the Pacific Oyster (*Crassostrea gigas*) in the Chesapeake Bay was narrowly averted when an experiment with triploid oysters failed. In this incident, a percentage of triploid oysters reverted into diploid organisms capable of reproduction (box 3-6) (12) but were removed from the bay before spawning occurred.

SOURCE: Office of Technology Assessment, 1995.

[3] Genes coding for specific traits isolated from one organism, copied, and transferred to another organism.

BOX 3-4: Assessing Environmental Risks of Aquatic Genetically-Modified Organisms

Risk assessment is a systematic process used to identify risks posed by certain activities to human health or to the environment. Risks are then evaluated and compared to benefits of the same activities. Results of the evaluation subsequently are used to develop public policy. Some analysts describe risk assessment as a method that connects science to policymaking (100).

The risk assessment process has been used widely in determining risks of activities to public health. For example, exposure to specific chemicals at known concentrations over a certain period of time may cause illness. Information from previous exposures can be used to estimate "safe" levels of exposure and thus assist in creation of public policy.

In 1993, the National Research Council presented a framework to adapt the risk assessment process to ecological risks (100).[a] The Council defined ecological risk assessment as "the characterization of adverse ecological effects of environmental exposures to hazards imposed by human activities." Five components contribute to the ecological risk assessment process:

- *Hazard identification*: The determination of whether a particular agent poses health or environmental risks sufficient to warrant further scientific study or immediate management action.
- *Exposure-response assessment*: Evaluation of the link between the magnitude of exposure and the probability that the potential effects will occur. For example, if a large number of sterile triploid organisms escape from an aquaculture facility, there may be a high probability of competitive interaction with native organisms but low incidence of reproductive activity.
- *Exposure assessment*: Determination of the extent of exposure before or after regulatory controls. Exposure can include nonchemical stresses such as the introduction of a new species.
- *Risk characterization*: Description of the nature and magnitude of the risk, including uncertainty, presented in a way that is understandable to policymakers and the public.
- *Risk management*: Formulation of public policy to manage risks and balance societal needs using information generated from the previous steps.

This framework might be used to assess ecological risks posed by using genetically modified organisms (GMOs) in aquaculture and to develop appropriate policy regulating their use. Several problems exist, however, in applying this framework generally to decisions about the management of natural resources and, specifically, to aquatic GMO regulation and decisionmaking.

Politicians, regulators, scientists, and private property owners debate the need for and effectiveness of using risk assessment and its integral valuation and cost benefit analyses as a touchstone for environmental policy. Proponents of risk-assessment procedures for evaluating development and regulatory decisions typically hail the structure and uniformity it affords to contentious issues. Opponents claim that economics as a driving decision-making tool downplays the importance of aesthetic, moral, cultural, and historical values that require the preservation of nature (122).

Although methods have been developed for assigning dollar amounts to ecological values, uncertainties associated with their application remain high (100,122). It generally has been easier to develop techniques to determine economic values for resource "use" values (such as boating and hunting), than for resource "nonuse" values (such as spiritual appreciation or preserving a legacy for future generations). Assigning economic values to nonuse values requires subjective evaluation and results are variable depending on the evaluator's geographic location, employment, and education, as well as assessment method.

Lack of information and lack of a track record with newly developed methodologies (2) make it especially difficult to assign values to risks posed by aquatic GMOs. Each aquatic GMO has specific traits affecting its persistence, competitiveness, and adaptability in natural ecosystems (74). Adverse genetic and ecological effects of released aquatic GMOs will depend on characteristics such as the nature and degree of change in the physical characters and performance of the GMO; potential for the GMO to disperse, reproduce, and interbreed; and the GMO's potential for adaptive evolution. Uncertainties in behavior of aquatic GMOs make it problematic to accurately predict long-term environmental consequences of releasing them into an ecosystem. Thus, the absence of previous experience with and population records for aquatic GMOs may continue to make them difficult candidates for the ecological risk assessment process.

[a] The 1993 framework was redesigned from an earlier, more generalized version: National Research Council 1983, Risk Assessment in the Federal Government: Managing the Process (the "Red Book").
SOURCE: Office of Technology Assessment, 1995.

Agencies responsible for overseeing environmental release of aquatic GMOs include the U.S. Fish and Wildlife Service (FWS), National Marine Fisheries Service (NMFS), and various state agencies overseeing aquatic resources. FWS and NMFS have mandates to protect the genetic integrity of wild stocks, aquatic habitat, and biological diversity. For example, under the Lacey Act, the FWS has authority to control impacts from migratory species, exotic species, or any aquatic species that cross state lines. Likewise, if the release of aquatic GMOs is likely to have an impact on threatened or endangered species, the FWS or NMFS will have responsibility to oversee these activities under the Endangered Species Act (ESA). The FWS and NMFS, however, lack specific mandates for regulating development and production of aquatic GMOs (74).

Because federal agencies have restricted jurisdiction over state waters, certain states have created their own laws regulating the release of GMOs into the environment (139). Certain of these regulations go beyond the provisions of the Coordinated Framework and subsequent federal regulations to address key loopholes or procedural ambiguities (74). Most of the state regulations, however, are aimed at GMOs in general rather than aquatic GMOs specifically (North Carolina Gen. Stat. §106-772 (1994);[4] Minnesota Statutes Chapter 116C.91-.98, as amended by 1994 Session Law, Chapter 454).

Aquatic organisms pose additional problems for regulation because they may cross national boundaries. Therefore, international policies governing the release of aquatic GMOs also are necessary. Agencies such as the Organization for Economic Cooperation and Development (OECD), the International Council for Exploration of the Seas (ICES) and the Food and Agriculture Organization of the United Nations (FAO) have investigated policy issues raised by the release of aquatic GMOs (74).

Recent examples of international collaboration for forming policy to govern the release of aquatic GMOs include an ICES Code of Practice, an FAO Review of Biotechnology in Aquaculture, and a workshop sponsored by the OECD held in June 1993 entitled "Environmental Impacts of Aquaculture Using Aquatic Organisms Derived Through Modern Biotechnology" (105). Amendments to the ICES Code of Practice in 1990 address concerns raised by aquatic GMOs (27). The amendments call for: any person or organization involved in "genetically modifying, importing, using or releasing any genetically modified organism" to obtain a license; risk assessment to determine the potential effects aquatic GMO release could have on the environment; initial release of GMOs to be performed with reproductively sterile organisms to reduce potential genetic impacts on the receiving population; and more research on ecological effects modified organisms may have in the environment (27).

Issue: Consequences of Releasing Aquatic GMOs into the Environment

Undesirable changes in wild gene pools may occur if cultured organisms interbreed with wild individuals. Wild-type genes could be replaced by the introduction of new genes from the cultured organisms, resulting in a loss of natural genetic variation (box 3-5) (117). Loss of genetic variability in wild populations also could restrict future options for hatchery programs and aquaculture breeders. Then, breeders relying on wild genetic material to increase genetic diversity in their captive broodstocks may be unable to

[4] This law has a "sunset" provision that automatically repeals the legislation on September 30, 1995, if the North Carolina legislature does not renew it (51).

find sufficient variety of wild genetic material (74,126).

Another undesirable change caused by cultured organisms interbreeding with wild individuals is the introduction of deleterious genes into a wild population. Wild organisms are specifically adapted to the ecosystem they inhabit. Genes and gene combinations in wild populations may determine coloration, swimming stamina, disease resistance, and other qualities necessary for survival (64). Genetic traits useful for cultured species, such as docility and rapid growth, may not be beneficial for survival in the wild. Thus, reproductive success of escaped farmed fish and of hybrid offspring produced from cultured fish interbreeding with wild fish may be considerably less than reproductive success of wild fish (box 3-5) (109,118).

Cultured organisms may cause undesirable changes in wild populations by upsetting gender balances as has been observed in some hatcheries (126). It is often advan-tageous to culture monosex populations because one sex may exhibit superior qualities such as faster growth rates (31). A large number of either male or female organisms released into the environment, produced by technologies such as direct feminization or masculinization, might produce skewed populations after mating. Subsequent population sizes could be reduced by inbreeding caused by distorted sex ratios (126). This may be of particular concern for some species, such as some salmonids, that spawn once and die.

Techniques to induce sterility are not always effective. Producing organisms with three sets of chromosomes (triploid organisms) sometimes is not 100 percent successful (box 3-6). In some bivalves, the percentage of triploid individuals ranged from 63.4 to 88.4 using various techniques (124). In finfish, pressure and temperature shocks can be 94 to 100 percent efficient in inducing triploidy (technique used to produce sterile organisms) (85,94). Incomplete triploid induction may lead to the inadvertent release of fertile individuals that subsequently interact with wild species or establish new breeding populations of non-indigenous species (74).

Even when sterility induction is successful, some triploid organisms may engage in

BOX 3-5. Genetic Dilution by Introgressive Hybridization

Striped bass (*Morone saxatilis*) (also known as Rockfish in the Chesapeake Bay) is a popular game and food fish, native to many Atlantic coastal states. Hybrid striped bass are produced by crossing striped bass with white bass (*Morone chrysops*). The hybrid offspring are fertile and can mate with either parental species or other hybrids. Interbreeding of hybrid striped bass and indigenous striped bass has been documented in areas where these fish coexist (26,42,60).

Stocking of hybrids for sport fishing was widespread in the Chesapeake Bay area in the 1980s. At one time it was estimated that hybrid bass may have comprised as much as 20 percent of the total winter population of striped bass in the Maryland segments of the bay (60).

Striped bass native to the Chesapeake Bay are uniquely suited to their environment. One special adaptation is the production of floating eggs that are able to withstand frequent tidal changes. The eggs remain suspended in the water column instead of sinking to the bottom where they could be covered with silt and destroyed (76). Striped bass from other areas outside of the bay and hybrid striped bass do not share this unique characteristic (116).

Bass lacking the ability to produce floating eggs may not exhibit high reproductive rates in the Chesapeake Bay ecosystem. Therefore, large numbers of hybrid striped bass, interbreeding with native striped bass could result in lower reproductive success and potentially lead to severe population declines in the native striped bass (60).

SOURCE: Office of Technology Assessment, 1995.

reproductive behavior. If sterile organisms attempt to spawn, they may prevent members of the wild population from fertilizing eggs. Additionally, if these organisms produce sperm they could "fertilize" normal eggs rendering them inviable (32). Large numbers of sterile individuals attempting to spawn could cause natural populations to decline (74).

Certain genetically modified organisms introduced into natural environments may also interfere with ecosystem functioning by altering important species interactions. For example, fish with introduced growth hormone genes may have higher metabolic rates and attain larger sizes at a given age than wild fish. The larger fish might then out-compete smaller, unaltered fish for food, habitat resources, or spawning sites (74). Additionally, faster growing fish may have larger mouth gapes enabling them to use new prey species or consume larger size classes of traditional prey species (56,73). Genes that extend tolerances of physical factors also might permit altered species to extend their geographical range and destabilize new ecosystems (74).

BOX 3-6: Is Induced Triploidy Reversible?

In June 1993, experiments were conducted on introduced triploid Japanese Oysters (*Crassostrea gigas*) in the York River, Virginia, a section of the Chesapeake Bay (154). Each oyster was tested to ensure triploidy before placing it in the river. After four months, one of the oysters was found to be diploid and thus capable of reproducing. Follow-up examinations revealed that many other oysters (20 percent) had become diploid or were mosaics of triploid and diploid cells (indicating partial reversal). An evaluation of the process used to create the triploid organisms showed that the procedures had been followed correctly. The triploid oysters had reverted by progressively replacing triploid cells with diploid cells.

The experimental introduction into the wild was halted when it was found that these organisms were capable of reproduction. Although reproduction could have taken place, cold water temperatures are believed to have prevented the introduced organisms from reproducing in the Chesapeake Bay (12).

The incident described above, though unprecedented, raises the question of reversible triploidy in other organisms. Triploid grass carp, tilapia, and rainbow trout have been introduced into aquatic habitats or raised in aquaculture for some time. What is the potential for these organisms to revert to the diploid state and reproduce? More research is needed to answer these questions and to prevent potential problems.[a]

[a] In 1995, the Biological Risk Assessment Research Grants Program (administered by the National Biological Impact Assessment Program) awarded $160,000 to the Haskin Shellfish Research Laboratory to investigate this problem. A study, entitled "Triploids for Biological Containment: The Risk of Heteroploid Mosaics," will take two years to complete.
SOURCE: Office of Technology Assessment, 1995.

Issue: Consumer Health and Safety Concerns

Human health could be affected by the use of biotechnologies if food derived from these organisms contains harmful substances. There are concerns that biotechnology proce-dures, such as gene transfer, could cause an organism to produce higher levels of existing toxins, novel toxins, or to become resistant to naturally occurring toxins and thus accumulate high levels in their tissues (74).

Toxins in commonly consumed fish and shellfish have been shown to come from external sources. Some scientists, therefore, have argued that transgenic fish and shellfish are generally unlikely to produce novel toxins (8,104). And, although some aquatic plants do produce toxic substances, several arguments suggest that current gene transfer techniques have a low likelihood of stimulating the production of new toxins. First, the production of toxins usually is a complex process that involves several steps. Transfer of one or a few genes into an algael species that does not normally produce toxins is unlikely to initiate production of new toxins. Second, knowledge about the production of toxins and their distribution in

marine algae is extensive. The availability of this information could make it possible to predict which species might produce new toxins. Transgenic aquatic plants capable of producing toxic substances could be screened for the presence of harmful products prior to permitting their commercial culture (74).

Allergens present a second health and safety concern related to use of biotechnology in aquaculture. Foods derived from transgenic fish, shellfish, or aquatic plants could contain proteins not normally found in the parent species or proteins produced at higher-than-normal levels. Some of the introduced or higher-than-normal levels of proteins could cause allergic reactions in susceptible consumers (52).

Correct identification of aquatic GMOs that might elicit food allergies is difficult because of an inadequate database and lack of conclusive information on the allergenicity of introduced proteins (59,74). Comprehensive screening methods for predicting which foods derived from aquatic GMOs could elicit allergic reactions require further investigation (74). To date, however, presence of a food allergen has not been a basis for keeping a product off the market.[5] Consumers generally rely on food labels to avoid consuming known allergens (74). Avoidance of allergens in

BOX 3-7: Religious and Ethical Concerns

Opposition to the use of biotechnology in aquaculture may arise from strongly held religious or ethical beliefs. Some groups believe that it is immoral to tamper with the sanctity of life. Transferring genes from one organism to another may be equated to "playing God" or "interfering with nature." Other religions hold that all life forms have been created in the best form and that organisms should not be altered by humans except to return deviations to their original form (23).

The nature of the transferred gene also may cause concern among specific interest groups. The transfer of genes of human origin into an organism used for consumption by humans might be unacceptable to some people. Some religions believe that a gene retains the essence of its original host. Thus, consuming an organism containing a copy of a human gene would be forbidden on religious grounds (23).

Other groups may be concerned that genes from animals whose flesh is forbidden for consumption may be present in organisms grown for food. This group could include vegetarians who may not want to eat plant materials that contain genetic information from animals (23).

Some animal rights' activists may object to technology they perceive to cause suffering in cultured species. For example, in an experiment to produce animals with leaner meat, pigs were injected with the human growth-hormone gene (51). The transgenic pigs attained leaner meat but also became arthritic. Animal rights' groups protested the use of this technology due to the suffering of the pigs (23).

It is possible that similar situations could arise in the aquaculture industry. For example, in an experiment with transgenic sockeye salmon (*Oncorhynchus nerka*), an introduced growth-hormone gene produced rapid growth that led to skeletal deformities (74). The observation of deformities in the fish might lead people to conclude that the fish had suffered as a consequence of the procedure and could result in protests.

Increased use of gene transfer technologies in aquaculture may bring religious and ethical concerns to the forefront. Several solutions have been proposed to address these concerns. First, attempts could be made to find gene donor sources from closely related species and not from controversial sources such as humans or consumption-restricted organisms. Second, foods that contain gene products from culturally-prohibited sources (e.g., products derived from pigs or animal flesh) could be labeled accordingly. And third, educating consumers about the biotechnology methods used to produce the organisms might help to reduce public concern over consumption of these substances. Consumers, for example, might be informed that the DNA used in a particular process was synthesized in a laboratory rather than removed from an animal (23).

SOURCE: Office of Technology Assessment, 1995.

[5] Pioneer HiBred, a company that develops and markets seeds, ceased research on commercializing genetically-engineered soybeans when studies showed that the soybeans elicited allergic responses in some consumers (50).

foods derived from transgenic fish or shellfish would therefore require that these foods be labeled as such. The FDA has not yet issued a decision on this issue (51,75).

Issue: Patenting of Aquatic GMOs

In a series of decisions in the 1980s, the Supreme Court ruled that genetically manipulated microorganisms, plants, and multicellular animals could be patented (29,38,37, 74). To date, four transgenic mice have been patented in the United States (17,54) and at least 180 animal patents are pending (4).

Patenting life generates many legal questions as well as religious and ethical concerns (box 3-7). For example: What do patents cover--one organism or a technique? What are the provisions for royalties? How are patents to be issued? How is proprietary protection granted? These questions are beyond the scope of this report but are discussed in detail in the Office of Technology Assessment Special Report "New Developments in Biotechnology: Patenting Life" (138).

Some biotechnology applications in aquaculture, such as gene transfer or chromosome set manipulation, may lead to future attempts to patent modified organisms. Patenting aquatic GMOs could be beneficial to the aquaculture industry in several ways. Patents for GMOs might provide economic incentives through royalties to inventors for development of genetically modified lines of cultured organisms. Patents for GMOs also might facilitate technology transfer through full disclosure requirements of techniques used to modify the organism in the patent application (74,78).

Conversely, patenting aquatic GMOs could harm the aquaculture industry. Patent holders could charge prohibitively large royalties for original broodstock effectively limiting entry to larger operations. Broad patents granted for an entire species could limit research, testing, and commercialization of aquatic GMOs (54,74). Additionally, opponents of patenting life forms argue that patenting life might lead to suffering of transgenic animals and reflect an inappropriate sense of human control over animal life (box 3-7) (74,138).

Issue: Use of Biotechnologies and Attitudes toward Environmental Protection

Some believe that extensive use of these technologies may lead to a society opting for changing organisms rather than preserving, protecting, or restoring the environment. Technologies such as gene transfer and chromosome set manipulation can alter organisms in such a way that they can tolerate degraded environments. Altered traits may allow GMOs to survive in impaired environments. For example, acid resistant hybrid brook trout have been developed for stocking in Adirondack lakes affected by acid rain (122). Similarly, the "saugeye" (a cross between a walleye and a sauger) lives in polluted waters where walleye cannot survive (122). Such technologies could influence society to respond to environmental degradation not by addressing the reasons for the impairment but rather by altering managed species to accommodate new conditions (74,122,139). Genetic modification, therefore, poses questions about our societal values and the management of aquatic ecosystems.

A similar concern is that emphasis on aquatic GMOs, highly tailored to human desires, will encourage our society to abandon efforts to rebuild and sustain natural fish stocks and the ecosystems on which they depend. In contrast, however, it is also argued that higher production rates in aquaculture made possible by new biotechnologies could help to reduce fishing pressure on wild stocks.

Issue: Research and Funding Priorities for Biotechnologies Used in Aquaculture

The potential of some modified organisms to have unintended effects on the environment and consumer health and safety has led to debates on research and funding priorities for

biotechnologies used in aquaculture. Research on biotechnology has focused traditionally on development of methods and the benefits of their application. Little research has evaluated the potential impacts that modified organisms may have on the environment. The National Biological Impact Assessment Program (NBIAP), managed by USDA, is one federal research grant program designed to investigate concerns regarding environmental effects of biotechnology. Funding for this program, which evaluates the potential risks of biotechnology research conducted by the Department of Agriculture, has been criticized as inadequate (74).[6]

Additional criticism of current funding priorities in aquatic biotechnology is directed towards choice of technologies investigated. Past research funding is criticized for emphasizing newer, more glamorous technologies, possibly at the expense of older proven technologies. For example, traditional selective breeding has been highly successful in aquacultural contexts but some argue that it is not used widely enough. Research funding, generally allocated in short segments (typically two years), also discourages research on selective breeding due to time constraints. A fragmented aquaculture industry largely composed of small producers with few resources cannot afford to initiate long-term breeding programs. Thus, most research on selective breeding has to be carried out by governments and, to some extent, universities. A few federal laboratories are engaged in traditional breeding activities, but studies seem to focus on only a few major species and a few traits (74).

BIOTECHNOLOGY APPLICATIONS AND BENEFITS

Many biotechnologies used in aquaculture are developed to increase production, reduce costs of production, manage disease outbreaks, raise the value of currently cultured organisms, or result in the culture of new species (table 3-1). Several biotechnologies, including gene transfer and selective breeding, focus on reducing the amount of time needed to bring a product to market. Long production cycles often distinguish aquaculture from traditional land-based agriculture. Terrestrial livestock, such as poultry or cattle, have production cycles measured in weeks or months while production of aquaculture products may be measured in years (most cold water species such as salmon may grow to a marketable size after two to three years) (31). The transfer of growth hormone genes into coho salmon produced transgenic fish that on average were 11 times heavier than non-transgenic controls (28) (box 3-8). Traditional breeding also has been effective. Coho salmon (*Oncorhynchus kisutch*) selected for rapid growth over four generations were 60 percent heavier after eight months of salt water grow-out than fish at the same stage in the first generation (31,63). Combining selective breeding with marker-assisted selection (identifying specific sequences of DNA associated with desirable traits) could also increase growth rates. DNA marking or introduction of known DNA segments could be used for tracking purposes.

Higher production rates also may result from using technologies to modify organisms so they can tolerate new environments (box 3-8). In some instances, hybridization has been used to produce organisms more tolerant of adverse conditions than either parent species (122). Likewise, gene transfer has the potential to affect the ability of an organism to live in a different environment. For example, transfer of a gene that encodes an "antifreeze protein" from winter flounder (*Pseudopleuronectes americanus*) to Atlantic salmon (*Salmo salar*) (41) (box 3-8) may increase the salmon's tolerance to freezing conditions, leading to increased salmon production in northerly regions.

Raising organisms in high densities can lead to mortality from stress and subsequent disease outbreaks. Various biotechnologies,

[6] Funding for this program was approximately $1.7 million for fiscal year 1994 (49).

such as new vaccines, are aimed at reducing disease outbreaks. Quick and accurate methods for diagnosing disease outbreaks could help to ensure rapid treatment before organisms suffer significant mortality. Gene transfer, marker-assisted selection, as well as selective breeding for low response to stress offer the possibility of producing organisms better able to resist diseases (31,40,74).

Several biotechnologies offer ways of increasing the value of aquacultural products.

BOX 3-8: Potential Benefits of Gene Transfer

Gene transfer technologies, or the ability to transfer desirable traits from one organism to another, may hold great promise for aquaculture producers. Gene transfer might be used to enhance natural growth or modify environmental tolerance of cultured aquatic organisms.

Previous attempts at raising levels of growth hormone by injection in fish were time consuming and impractical to implement on a large scale. Recent experiments may lead to a more efficient method of introducing hormones from one aquatic organism to another. Fertilized eggs from coho salmon were injected with a growth hormone gene derived from sockeye salmon (28). After 14 months of growth, the transgenic salmon were on average more than 11 times heavier than untreated controls. The largest fish was 37 times heavier than the average controls (28). The transgenic salmon also exhibited the silver coloration characteristic of more mature fish physically ready to begin the migration from freshwater to saltwater (28).

Results from this experiment may eventually lead to products ready for market sooner leading to higher profits for producers. Increasing the rate at which the physical transformation needed for saltwater growout occurs could simplify the culture process as well as reduce high costs associated with raising young fish in a hatchery for extended periods.

Environmental tolerance is another production characteristic that may be amenable to alteration by gene transfer. Some fish, for example the winter flounder (*Pseudopleuronectus americanus*), can survive in "supercooled" seawater because they have specific proteins which prevent their blood from freezing (41). These proteins prevent ice crystal formation in a manner similar to the way antifreeze prevents water in a radiator from freezing.

Salmon lack antifreeze proteins and, thus, water in the blood can freeze at temperatures below -0.7º C (30.7º F)(freshwater freezes at 0º C or 32º F), resulting in mortality (74). The transfer of the gene coding for antifreeze protein from winter flounder to Atlantic salmon therefore may be able to extend the northern range for net pen salmon farming. To date, researchers have transferred the antifreeze gene to salmon, but, the protein is not yet produced at high enough levels to confer significant freeze resistance to the fish (31,41).

SOURCE: Office of Technology Assessment, 1995.

Aquaculturists already use these techniques. For example, production of monosex female salmonids allows salmon farmers to produce fish that mature later and grow to larger sizes than male salmonids. Larger salmonids bring in higher prices at the market. Monosex female rainbow trout are cultured widely in North America for this reason (31). Likewise, triploidy, a technique used to produce sterile organisms, is used to culture rainbow trout and Atlantic salmon on a commercial scale in North America and Europe. Triploid Pacific oysters (*Crassostrea gigas*) are produced to suppress reproductive maturation leading to oysters with higher meat quality during summer months (3). Strategies that improve the nutrition of the marketed product such as a lower fat diet of the cultured organism also can raise the product's value by making it more desirable to the consumer. Likewise, selective breeding experiments over three generations have produced catfish with 29 percent higher body weights and higher percentages of edible body tissue (35).

Biotechnologies can facilitate culture of new species. New species must be marketable and amenable to culture from an early life stage to market size in captivity (31). Biotechnologies that increase the economic benefits of aquaculture production are important as well as to the development of a new culture species. For example, producers

of each newly cultured species can take advantage of technologies that increase production to meet market requirements, treat diseases particular to the species, and provide nutritionally complete and economic diets for each life history stage (31).

Use of biotechnology in aquaculture has environmental and social consequences as well as economic ones. First, wild fish stocks may be affected by interbreeding with escaped fertile organisms or by new competition from self-sustaining populations of non-indigenous species. Using sterile triploid organisms such as grass carp (*Ctenopharyngodon idella*), could reduce possibilities for this non-indigenous species to increase its abundance and displace other native species when released in the wild (74). In the future biotechnology techniques may create organisms incapable of surviving in the wild after escape (similar to domestic chickens or cattle), therefore reducing environmental impacts (51). Second, juveniles of some species raised worldwide such as shrimp, milkfish (Chanos chanos) and eels (Anguilla spp.) are collected from the wild due to an inability to cost-effectively complete their life cycles in captivity. Information on the life cycles of these organisms would be useful for developing practical spawning techniques that could reduce the collection of juveniles from the wild (31). Third, developing feeds using complete proteins derived from enhanced plant sources instead of fish meal could help to reduce the overharvest of organisms used to manufacture fish meal. Fourth, biotechnologies that lead to higher production rates or more desirable products might reduce pressures on wild stocks.

In addition to protecting wild stocks by reducing harvesting pressures, biotechnologies such as cryopreservation (storage of genetic material in liquid nitrogen) offer the potential to preserve unique genetic resources. In emergency situations, when local stocks or entire species face extinction, cryopreservation can be used to store genetic material from these organisms. For example, sperm from the endangered Redfish Lake sockeye salmon (*Oncorhynchus nerka*) has been collected and stored using this technique (134). A drawback of relying only on cryopreservation to conserve genetic resources is that it arrests the ongoing evolutionary adaptation of living organisms to their constantly changing environments, a process which is essential for long-term persistence of a species (74).

Biotechnological applications in aquaculture products may also protect the consumer. Breeding disease-resistant organisms, transferring genes for disease-resistance, and using vaccines can reduce disease outbreaks. Timely diagnosis of disease could reduce the need for emergency use of antibiotics or other chemicals (31). Reduced use of antibiotics may address concerns about formation of antibiotic-resistant bacteria potentially causing disease problems in wild and cultured species or humans, and the possibility of residues of these substances showing up in food products (10,36,90).

CONCLUDING REMARKS

Biotechnology plays an important role in the development of aquaculture. Biotechnologies are used to induce reproduction; hasten growth and development; produce monosex populations; alter other performance traits such as temperature tolerance; produce sterile organisms; map and store genetic material; introduce new traits not normally found in the species; improve the health of cultured organisms; and improve the quality and diversity of seafood products available for consumers (25,31). These technologies have great potential to continue to improve the productivity and profitability of the aquaculture industry. Traditional technologies such as selective breeding can be made more effective by combining them with newer methodologies such as DNA marking or marker-assisted selection.

Benefits from biotechnologies used in aquaculture have been realized and will

continue to increase. The risks to the environment, human health, and other social concerns, however must be carefully evaluated before these technologies are widely adopted. To date there exist only voluntary performance standards for assessing and managing ecological risks of genetically modified fish and shellfish (2). A better documented database of risk assessment results are needed to establish appropriate regulations governing research, use, and release of genetically modified organisms that pose risks to the environment and human consumers. Guidelines could be established with involvement from the relevant federal and state agencies as well as representatives of the aquaculture industry, commercial fishing industry, environmental groups, and other stakeholders. Many of the biotechnologies perceived to pose the greatest risks to the environment or human health are not yet widely used, therefore, opportunity exists to prevent problems before they occur.

4
Bird Predation

INTRODUCTION

Birds are responsible for sometimes serious production losses for aquaculturalists. Estimates of losses to predators at aquaculture facilities vary from as low as 8 percent to as high as 75 percent of total fish production (33). In dollar amounts this translates to annual economic losses of $49 to $4,120 per trout raceway in central Pennsylvania (108); $20,000 in a two-week period for baitfish in Arkansas (65); and up to $3.3 million per year on catfish farms in the Mississippi Delta (15,133).[1]

An unprotected aquacultural operation presents a textbook example of an optimal foraging situation for predators because of the high prey density and the potential for a high foraging success rate (107). At least 65 bird species have been identified as predators of aquacultural crops in the United States (107) (box 4-1). Numbers and types of avian predators vary depending on facility type, cultured species, and management techniques. Common bird predators at aquaculture facilities include double-crested cormorants, great blue herons, great egrets, snowy egrets, little blue herons, black-crowned night herons, ring-billed gulls, and belted kingfishers (107).

A widely applicable solution to bird predation problems in aquaculture has not yet been discovered and one is not likely to arise in the near future. Aquaculture today is so diverse that it is unrealistic to expect one methodology to manage predators effectively in all types of facilities. The most effective approach to deterring bird predators to date is to use a variety of non-lethal techniques, changed often and perhaps supplemented with periodic lethal control with a proper permit.

CONGRESSIONAL INTEREST

Most of the bird predators at aquaculture facilities are protected by the Migratory Bird Treaty Act of 1918. Federal agencies are involved in developing non-lethal methods to control predators exploiting agricultural crops and for issuing permits, when warranted, to kill the predators. The Fish and Wildlife Service works with the U.S. Department of Agriculture, Animal and Plant Health Inspection Service/Animal Damage Control to ensure permits are warranted and issued in a timely fashion. USDA's Office of Animal Damage Control also develops and implements depredation control measures.

Congressional interest in the problem of bird predation in aquaculture stems from its oversight of the federal agencies charged with enforcing depredation permits and developing predator control methods. One example of a potential Congressional role regarding bird predation and aquaculture includes creating a certification program to curb predation problems. Congress could require the U.S. Fish and Wildlife Service to certify aquaculture facilities with a predator-check permit. The predator-check permit could ensure that every new aquaculture facility consider the potential for predation problems during the original siting and approval process. The certifi-

[1] The $3.3 million figure did not include the cost to harass birds or to protect cultured stocks, estimated at $2.1 million per year. Thus, the total annual loss of catfish to cormorants in the Mississippi Delta was estimated at $5.4 million (133).

BOX 4-1: Mammal Predation and Aquaculture

At least 15 mammal species have been identified as predators at aquaculture facilities including seals, sea lions, muskrats, mink, river otters, Norway rats, raccoons, feral cats, bears, and skunks (107).

Unlike the situation for birds, a systematic attempt is not made at the national level to monitor population trends of most freshwater and terrestrial mammals over large regions of the country. The task of monitoring and setting policy for many freshwater and terrestrial mammals resides with the natural resources agency in each state and may be regulated through open seasons, a permit system, and bag limits. Producers experiencing damage from regulated species, such as game species or furbearers, are encouraged to manage the offending species during established regulated seasons.

Where damage is severe and where non-lethal methods have not provided satisfactory control, the state game warden may issue a damage kill permit. A damage kill permit will describe the species and number of individuals allowed to be taken and the time period within which this take shall occur. In most cases, the carcasses of the animals taken while under the provisions of the permit must be turned over to the warden and an annual report that summarizes the take made by the permitee must be filed with the state wildlife agency (107).

The U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) have jurisdiction over management decisions relating to federally listed endangered or threatened mammals and all marine mammals. Marine mammal species protected under the Marine Mammal Protection Act of 1972 (MMPA) and/or the Endangered Species Act of 1973 (ESA) may have sufficient data available to monitor population trends. According to NMFS, this office has published information on all marine mammal stocks in U.S. waters, completed stock assessments for marine mammal populations that interact with fisheries, and detailed information on pinniped populations for which there have been documented interactions with aquaculture (including harbor seals, gray seals, California sea lions, and Steller sea lions) (99).

Amendments to MMPA in 1994 required a study of marine mammal interactions with salmonid fisheries in the west (due October 1, 1995) and an examination of interactions between pinnipeds and aquaculture in the Gulf of Maine (due April 30, 1996) (20,99). These studies may provide suggestions for future aquaculture/marine mammal interaction programs.

SOURCE: Office of Technology Assessment, 1995.

cation program could rely on advice at the pre-permit stage from engineers, ornithologists, and others familiar with predation problems. Permit processors could ensure that potential new aquafarmers are aware of sources and availability of good advice and management techniques to prevent problems before starting the culture operation. Finally, the permit could require the industry to use facility construction that takes advantage of the best available and most economical technologies for excluding predators.[2]

Providing compensation for losses incurred at aquaculture facilities from predators frequently is espoused as a solution to predation problems. In response to this proposed solution, Congress might require compensation be given to all aquaculture facilities that experience a specified level of economic damage due to

[2]The Scottish Salmon Growers Association (SSGA) adopted a Code of Practice relating to predators (22). This code specifies that new farms not be established close to known concentrations of predators; that adequate preventative measures be incorporated into all farms at the planning stage, and be regularly reviewed in the light of future research; and that it is the responsibility of salmon farm management to ensure proper procedures are adopted to reduce the impact of predators on farmstock. The SSGA plays an important role in the dissemination of information and research to improve the exclusion of predators from primarily salmon farms by non-destructive means. While the United States aquaculture industry includes production of diverse products, not limited to salmon, the SSGA Code of Practice might be used as a model for the National Aquaculture Association to use in establishing a similar predation-prevention program in the United States.

predators. However, there are faults with this approach. Compensation without a requirement to correct or limit the root cause of the problem would not prevent repeated future damage. Additionally, there must be a funding source to pay for compensation claims. Existing compensation programs for wildlife damage are funded primarily by fees imposed as a part of obtaining a hunting or trapping license (107). This could be viewed as penalizing the sporting public while others who benefit from wildlife are not assessed a similar penalty. Limited funds may lead to "first come, first serve" payments, with the possibility of individuals who experience late season damage being turned away for lack of funds.

Suggestions have been made that all aquaculturists pay a fee in return for the privilege of participating in the industry. These monies would be used to fund compensation for losses to predators and for research on control methods. Another suggestion for Congress is to provide incentives such as low interest loans or tax credits to those who retrofit existing facilities to exclude predators.

ISSUE IDENTIFICATION

Issue: Conflicts of Interest in Addressing Bird Predation Problems

Industry representatives, environmental groups, and consumers have conflicting viewpoints and concerns about wildlife predation at aquaculture facilities. Industry representatives complain of excessive economic losses caused by predators; of delays in acquiring depredation permits; and of failure by the U.S. government to compensate the industry for losses from predation. Environmental groups are concerned about unwillingness of some producers to rely solely on non-lethal methods of control and about real or perceived abuses of depredation permits. Consumer interest in predation problems may be spurred if prices of aquacultural products increase as producers factor in costs of mitigating predation problems.

Issue: Lack of Data Documenting Problems and Solutions

The general lack of reliable, easily accessible scientific data on the true extent of the physical and economic impacts of bird predators on aquaculture impedes progress toward resolving conflicts among stakeholders (107). Anecdotal accounts and extrapolations of data from small studies to broad, industry-wide application tend to dominate the information available on predation problems. To make reasonable approximations of economic impact of predators even on a single aquaculture facility, reliable data are required on number of predators, size and number of prey taken, and how long the predators fed.

To address predation problems with an accurate information base, the aquaculture industry must be willing to quantify and compare economic losses from predation with losses from other sources of mortality such as disease and weather (108,112). In some aquacultural facilities, the impact of predation might be insignificant relative to other problems, yet, managers may continue to devote capital toward deterrent options that may not be cost effective.

Few scientific studies have specifically examined the potential cause and effect relationship between aquaculture and bird populations (107). Even fewer studies have linked population increases or decreases or changes in behavior of wildlife directly to the development of aquacultural operations. Thus, although there is much speculation about the potential effects of these facilities on bird numbers and distributions (e.g., 92,93), hard evidence documenting effects of aquaculture facilities on wildlife populations generally is lacking. Like most wild animals, however, birds optimize and will adapt appropriately to opportunistic situations (box 4-2) (114).

Not only are data lacking on causal relationships between bird population changes and aquaculture facilities, but also on national or regional population trends for birds. Detailed information usually is available only for selected species in restricted locales. Lack of reliable data makes it difficult to determine whether a trend exists for a particular species or group of species over large areas such as states, regions, or the nation (107).

BOX 4-2: Short-Stopping Double-Crested Cormorants and Fish Farms

Fish farmers and others have speculated that the increase in number of wintering double-crested cormorants in the Mississippi Delta is due in part to the phenomenon of "short-stopping" of southward migrating birds attracted by the burgeoning aquaculture industry (133). Short-stopping refers to the premature termination of southern migratory movement well short of the normal wintering grounds in response to a particular stimulus, usually abundant food.

Verification of such hypotheses with hard scientific evidence, such as recovery of marked individuals or radio telemetry data, has not been made (107). Strong circumstantial evidence, however, seems to support the short-stopping speculation. Evidence shows the number of roosts and individual wintering cormorants in the Mississippi Delta area has increased since 1987 (133). It is not clear whether this represents short-stopping or simply increases in seasonal local populations.

It has been further speculated that some cormorants may eventually forego migrating altogether and establish a resident population in the Mississippi Delta (133). Other typically migratory species remaining longer in wintering or breeding areas or becoming year-round residents now present wildlife damage problems in certain areas (24,151). However, in the case of the double-crested cormorant, although many spend the winter in the Mississippi Delta in response apparently to the vast acreage of catfish ponds, the great majority still winters in coastal waters of the Gulf of Mexico (137).

SOURCE: Office of Technology Assessment, 1995.

Issue: Use of Lethal Methods to Control Avian Predators

Considerable debate surrounds the purpose, need, and effectiveness of lethal methods. If nothing is done to make a foraging site unattractive, avian predators removed via lethal methods are replaced quickly by other individuals of the same or different species (34). Rapid replacement of one predator by another suggests that elimination of individual birds may not be an effective solution to reducing bird abundance at fish farms. In fact, it has been claimed that no scientific data exist to show that removal, relocation, or elimination of individual bird predators has any long-lasting effect on reducing bird predator abundance at fish farms, nor does it alone reduce fish losses (34).

It is sometimes advised, however, that the authorized, legal killing of a few birds may be useful to scare off potential predators and to restore the effectiveness of other non-lethal deterrents (83). Proponents of lethal methods recommend that efforts be directed toward removing individuals that have learned to circumvent deterrents successfully rather than taking naive, ineffective feeders. This suggestion assumes that the person doing the killing can distinguish among individual predators. From the producer's perspective, lethal methods provide a visible means of eliminating offending animals and give immediate gratification (77).

Issue: Problems with Depredation Permit Process

All native birds in the United States either are protected by federal statute (Migratory Bird Treaty Act of 1918; Endangered Species Act of 1973) or are regulated as game by federal and state laws or regulations.[3] Provisions in the federal

[3] Seventeen species are regulated as game species; 23 introduced bird species receive no protection (such as house sparrows and European starlings).

acts, however, allow for the taking, under specified conditions and procedures, of protected species causing economic damage or presenting human health hazards (146).

The U.S. Fish and Wildlife Service, Division of Law Enforcement personnel reviews requests for and issues depredation permits. USFWS personnel also are required to monitor and enforce compliance with provisions of all permits--not just those to aquaculture--issued by the agency. Further, Division personnel are required to investigate any suspected cases of illegal taking of birds. Limited staffing and the need to cover considerable geographic areas within a region make monitoring for compliance and enforcement of permit provisions a monumental task.[4]

It is possible that violations of wildlife law go unchecked at aquacultural facilities. Some may result from lack of knowledge by operators about the law; others may be purposefully conducted violations with intent to eliminate unwanted wildlife. The regional supervisor for Region 1, USFWS Division of Law Enforcement described the situation facing him and his staff as follows:

There are an estimated 1,000 licensed aquaculture facilities in Region 1. It is believed that more than 90 percent of the facilities kill migratory birds. The estimate is based on off-the record comments from people in the industry and citizen complaints. Because of limited resources, we have been able to investigate only a fraction of the complaints received from the public and local officials (107).

Aquafarmers also have complaints regarding the depredation permit process, pointing to inconsistencies among state enforcement policies and to discrepancies between state and federal rulings.[5] Aquafarmers also complain about the lack of an incidental take clause within the depredation permit that would allow for the accidental killing of a limited number of birds not listed on a permit.

To address complaints about the permitting process and criticism of an inefficient permit record-keeping system, Congress could request regular progress reports from the U.S. Fish and Wildlife Service on the process for issuing depredation permits.[6] Congress also could request that USDA and USFWS conduct comprehensive surveys of aquaculture facilities to determine the extent of predation problems including species, estimates of losses, and methods of control.

The USFWS could be required to modernize its computer database program for bird depredation permits to attempt to answer critical questions--such as numbers of permits issued, and numbers of birds killed. Improved computer technology for the permit program might include applying geographic information system (GIS) methods toward resolving predation problems. Computer databases on the

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[4] Manual retrieval of records on permit data--which took approximately seven months to arrive at OTA, many in a different form for each USFWS region--exemplifies at least one shortcoming of the present system.

[5] Lack of agreement about a depredation permit between state and federal regulators led to a 1991 court case in *Pennsylvania: Aqua-Life* v. *Pennsylvania Game Commission Commonwealth*, No. 165 M.C. 1991.

[6] The USFWS, Division of Law Enforcement, has indicated the allocation process for depredation kill permits will be revised to include an objective and scientific basis for review (107). Current policy generally dictates that if the proper application is filed and base criteria are satisfied, a permit will be granted. In accordance with suggested revisions, permit requests would be reviewed by a panel, possibly consisting of representatives from permit authorities (USFWS, USDA), biologists, and independent industry representatives.

Decisions on the granting of requests for kill permits would be based on an evaluation of economic and physical impact to the operation, as well as the effects of take on the species involved. Where the predator population is determined to be unable to withstand significant reduction, or where justification for kill has not been made, a depredation permit would not be granted. The revised format would provide opportunity to monitor impacts of kill actions on ecological resources. The new format, however, may impede quick response to requests with justifiable need.

location of wildlife populations and their habitats, species status, hydrologic resources, and other environmental parameters could be used to improve aquaculture facility siting to reduce predation problems.

CONTROL METHODS

Much information is available on technologies to minimize predation by birds in aquaculture. None of the technologies, however, will guarantee 100 percent protection against predation losses. Control methods have to be effective, economically feasible, and environmentally safe. Although available technologies will provide some protection over varying periods of time, producers should not rely on one method to guard against losses. An integrated approach that combines a careful preliminary examination of facility location, design, construction, operation, and management for minimizing losses due to predators along with consistent application of different effective deterrent techniques will most likely provide the best protection from predation problems (box 4-3).

Methods of bird predator control at aquaculture facilities fall into four categories: facility siting, land husbandry, non-lethal, and lethal methods (table 4-1). None of the methods have proven 100 percent effective in deterring avian predators. Effectiveness of a particular control method will vary from facility to facility depending on such factors as facility type, size of cultured species, and management techniques (107).

Commercial production of catfish in large, contiguous ponds precludes use of

BOX 4-3. An Effective Bird Predation Control Program

Advice from several sources provides a realistic approach to bird predator control at most aquacultural facilities (83,112).

Before construction of an aquacultural facility:

- Evaluate chosen site to determine if it is the best possible site or if you are setting yourself up for predation problems that present technology cannot solve.
- Consider the size, shape, and layout of ponds.
- Get to know local ornithologists and enlist their help in determining bird populations, roosting sites, and behavior.

After construction of an aquacultural facility:

- Start your deterrent effort immediately. Discourage predators before they establish a feeding pattern.
- Frighten birds away before they land on the water's surface. It is much more difficult to get birds back into the air than to turn birds away while still flying. Once diving birds land, they can dive under water and avoid exposure to many harassment techniques.

Ongoing predator control methods:

- Use a variety of techniques and change the location and combinations of non-lethal controls to keep predators off-guard and to minimize the potential for habituation.
- Quantify losses from all sources: disease, water quality, and predation. Accurate data will help document losses due to predation and whether the losses are greater or less than annual predator control costs.
- With proper authorization, use lethal methods if necessary for enhancement of non-lethal methods.
- Report bird kills under permits accurately for numbers and species.
- Don't expect total elimination of a predator problem; strive for a reasonable reduction.

SOURCE: Office of Technology Assessment, 1995.

TABLE 4-1: Control Methods fro Avian Predators at Aquaculture Facilities

Control method	Technique	Predators affected[a]	Facility type	Comments on effectiveness[b]	Relative costs of control[c]
Facility siting and design	Avoid known predator roosts, rookeries, and migration routes	All	All	When flexibility exists for siting a facility, thorough review of potential sites in advance may preclude some predation problems.	Costs vary; less expensive when deterrents installed during construction rather than retrofitting
Good husbandry	Maintain clean facility	All	All	Simple, commonsense activities, such as cleaning up spilled feed, regularly removing dead stock, and controlling vegetation growth, can make a site less attractive to predators as well as prevent health and disease problems.	Minimal costs
Non-lethal methods					
Facility modification	Increase water depth in holding structure	Waders, ground feeders	Raceways	Increased water depth may prevent birds from wading, however, birds that typically use wading behavior can alter feeding methods and use diving and swimming techniques.	Variable costs
	Raise height of sidewalls of holding structure	Waders, ground feeders	Raceways	Raising height of sidewalls above the water's surface can place cultured stock out of reach of some predators; height required to keep predators away will vary with predator species.	High costs if facility is retrofit
	Increase slope of embankment	Waders, ground feeders	Ponds, raceways	Increased slopes around ponds or raceways can make it difficult for wading birds to reach the water's edge; gradual embankments duplicate natural feeding environ-ments and facilitate predator's access and feeding success.	High costs if facility is retrofit
	Remove perches and feeding platforms	Waders, aerial-divers, ground feeders	Ponds, raceways, net pens	Removing perches and platforms that might be used for feeding or hunting (such as light posts, electric wires, fence posts, and handrails) that are near or above culturing structures can eliminate or at least limit their usefulness to predators.	Variable costs
	Remove concealing cover and protective vegetation	Waders, aerial-divers, ground-feeders	Ponds, raceways	Removing cover and vegetation that conceals or protects predators can reduce their feeding success.	Low costs
	Roost/nest site dispersal	Waders, aerial-divers	Ponds, raceways	Forcing birds to relocate from a roosting site can reduce bird numbers on ponds; birds may not leave the general vicinity relocating to other undisturbed ponds or facilities within flight distance.	Moderate costs

TABLE 4-1: Control Methods for Avian Predators at Aquaculture Facilities (cont'd.)

Control method	Technique	Predators affected[a]	Facility type	Comments on effectiveness[b]	Relative costs of control[c]
Operational modification	Modify type of feed and feed delivery method	Aerial-divers, ground-feeders	Ponds, raceways, net pens	Floating feed attracts gulls and other surface feeding birds; non-floating pellets may reduce availability to predators; feed thrown carelessly may accumulate and attract predators.	Variable costs
	Alter on-site location of vulnerable stock	Waders, aerial-divers, swimming birds, ground feeders	Ponds, raceways	Predator activity is reduced in areas close to human activity; placing the most vulnerable or economically important stocks in structures close to activity centers may reduce losses to predators.	Low costs when space is available
	Careful selection of cultured stock	Waders, aerial-divers	Ponds, raceways	Certain biological characteristics among cultured stocks may influence their susceptibility to predators (e.g., depth occupied in water column).	Costs undetermined
	Provision of alternative food	Waders, aerial-divers, swimming birds, ground-feeders	All	"Buffer" food such as low-value fish may be placed in ponds at the peri-phery of the facility; abundance and ready access may make buffer food more vulnerable to predators causing them to leave higher valued species alone; results of method have been mixed; concerns exist regarding artificially increasing predator density with increased food supply.	Moderate costs
Auditory harassment	Predator distress calls (broadcast of a recording of a predator species' alarm call)	Waders, swimming birds, ground-feeders	Ponds, raceways, net pens	Effectiveness of method greatest when used at time predation problem first arises; response to playbacks varies with species, time of day, time of year, and distance predators are from speakers; may cause some birds to flock around sound; method subject to habituation.	Low costs
	Automatic exploders (small canons operated on bottled gas and controlled by electric timer)	Waders, aerial-divers, swimming birds, ground-feeders	Ponds, raceways	Effectiveness of method mixed; may be negative effects on cultured species; use not feasible in all locations, especially in areas with noise ordinances or when neighbors are nearby; method subject to habituation.	Moderate costs
	Pyrotechnics (explosive noise-making devices including cracker shells, bombs, whistlers, screamer rockets, and firecrackers)	Waders, aerial-divers, swimming birds, ground-feeders	Ponds, raceways, net pens	Effectiveness depends on firing range of device, weather conditions, experience and accuracy of operator; potential exists for non-target losses; method subject to habituation.	Moderate to high costs

TABLE 4-1: Control Methods for Avian Predators at Aquaculture Facilities (cont'd.)

Control method	Technique	Predators affected[a]	Facility type	Comments on effectiveness[b]	Relative costs of control[c]
	Sirens (similar to emergency vehicle sirens; can vary in pitch and attach to timers)	All	All	Method subject to habituation.	Low costs
	Electronic noise-makers	All	All	Results slightly more effective with mammals; effectiveness varies with intensity of noise and positioning; acoustic seal deterrents may pose negative effects on non-target species (e.g., drive whales and porpoises from feeding grounds; method subject to habituation.	Low to moderate costs
Visual harassment	Lights (streetlights, floodlights, flashers, strobe lights)	All	All	Effectiveness varies with predator species; may be more effective, at least initially, with nocturnal preda-tors; will temporarily blind and con-fuse predators and limit predation; method subject to habituation.	Variable costs
	Scarecrows and effigies	Waders, aerial-divers, swimming birds, ground-feeders	Ponds, raceways	Effectiveness varies with predator species; effects increase with incorporation of moving parts and when moved routinely to new locations; occasional human presence and use of pyrotechnics shot from near the effigy may reinforce the stimulus; method subject to habituation.	Low to high costs
	Predator decoys (models, silhouettes of hawks, owls, snakes)	Waders, aerial-divers, swimming birds, ground-feeders	Ponds, raceways, net pens	Effectiveness varies with predator species; method subject to habituation.	Low costs
	Reflectors (shiny-surfaced objects reflecting light)	All	All	Effectiveness varies with predator species; method subject to habituation.	Low costs
	Model airplanes	Waders, aerial-divers, swimming birds, ground-feeders	Ponds, raceways	Most effective when model planes fitted with pyrotechnic launches that haze birds as they attempt to land; birds already on water may dive to avoid the harassment; method limited by weather, flight obstruc-tions, need for frequent refueling; potential for crashing into pond and creating water quality problem.	Low costs
	Trained falcons	Waders, aerial-divers, swimming birds, ground-feeders	Ponds, raceways	Effectiveness limited by size of facility and finding interested and dependable falconer.	Costs undetermined

TABLE 4-1: Control Methods for Avian Predators at Aquaculture Facilities (cont'd.)

Control method	Technique	Predators affected[a]	Facility type	Comments on effectiveness[b]	Relative costs of control[c]
	Human presence	All	All	Effectiveness varies with use of supplements (pyrotechnics, recordings), size of ponds, and frequency of visits by humans; method subject to habituation.	Variable costs
Barriers	Perimeter fencing and protective netting	Waders, swimming birds, ground-feeders	Ponds, raceways, net pens, nearshore and offshore culture	Effectiveness varies with facility design and size and predator species.	Variable costs
	Water spray devices (stationary or rotating sprinkler units distributing jets or curtains of water over the water's surface)	Waders, aerial-divers, ground-feeders	Raceways, net pens	Provides both visual and auditory stimuli; reduces visibility of fish in water effectiveness varies with species and may be increased with greater water pressure and when operated cyclically rather than continuously.	Moderate costs
	Plastic sheet guards (Poly-ethylene sheeting suspended over gates of raceways)	Waders, ground-feeders	Raceways	Used to reduce predation by "stand and wait" predators such as common grackles; device can be cost-effective but may require increased personnel effort to perform routine maintenance chores.	Low to moderate costs
	Exclosure (any type of physical structure preventing an animal from gaining access to cultured stock; includes netting of entire facility or sepa-rate units and side netting or fencing)	Waders, aerial-divers, swimming birds, ground-feeders	Ponds, raceways	Effectiveness varies with size and design of structure; method subject to problems with structure failure, collapse during high winds or other inclement weather, entanglement of non-target and protected species in netting, hindering of routine maintenance operations, and secondary loss of stock when structure collapses into rearing pond	High costs
	Overhead wire grid (stainless steel wires or heavy gauge fishing lines suspended horizontally above water's surface)	Divers, swimming birds	Ponds, raceways, net pens	Size of grid must be adjusted depending on predator's size and feeding behavior; problems with overhead wire grids include excessive weight loading from ice or groups of birds perching on its supports, eventual weathering of material, maintaining sufficient support on long spans, and birds landing outside of the perimeter and walking into protected area	Moderate to high costs
	Top covers (tight fitting, framed covers mounted over culture units)	Waders, aerial-divers, swimming birds, ground-feeders	Raceways, net pens	Method may cause problems for routine facility maintenance or operation.	Moderate costs

TABLE 4-1: Control Methods for Avian Predators at Aquaculture Facilities (cont'd.)

Control method	Technique	Predators affected[a]	Facility type	Comments on effectiveness[b]	Relative costs of control[c]
	Electric wire and fencing	Waders, ground-feeders	Ponds, raceways, net pens	Effectiveness varies with feeding behavior of predators; method subject to habituation.	Moderate costs
Trap and release	Trap and release predators where allowed by law	All	All.	Where allowed by law, problems occur with disposing of captured animals; technique will not solve ultimate cause for conflict and may provide only temporary relief.	Moderate costs
Chemical deterrents	Repellents; include products such as ReJex-iT (product made from plant-derived chemical with grape-like odor) and A-C (alpha-chloralose) based compounds that sedate predators and allow for capture	All	Ponds	Use may be impractical because of human health and safety concerns, limits set by FDA for amounts of chemical contaminants allowed in consumable products, and predominance of chemicals designed for land-based applications.	New products
Lethal Methods					
Trap and kill	Trap and kill predators where allowed by law	All	All	Technique will not solve ultimate cause for conflict and may provide only temporary relief.	Moderate costs
Shooting	In most cases requires depredation kill permit	All	All	Technique will not solve ultimate cause for conflict and may provide only temporary relief.	Low to moderate costs
Toxicants	Use of toxicants subject to legal restrictions	Depends on chemical	Depends on chemical	Use of toxicants may be prohibited on wildlife in most states; "restricted use" products require pesticide certification.	Low costs

[a] Key to predators:

- Waders such as herons and egrets
- Aerial-divers such as gulls, kingfishers, osprey, pelicans
- Swimming birds such as cormorants, waterfowl
- Ground-feeders such as grackles, crows, magpies

[b] Habituation refers to the gradual diminishing of an animal's fright response to novel situations (107).

[c] Cost is relative to other methods; estimated by Parkhurst (107).

SOURCE: Office of Technology Assessment, 1995.

some effective control strategies such as netting or overhead wiring. Large ponds also provide ample central areas where birds find protection from many harassment technologies. Diving predators, the cormorant in particular, frequently escape harassment by vanishing underwater at the first sign of potential danger rather than taking flight. Organisms cultured in cages or net pens in open water may be subject to predation from marine fish, mammals, and birds.

Size of prey can bear on predation problems. For example, baitfish are small even as adults and the number of potential predators capable of efficiently handling such prey is large. Harvesting methods of cultured stock that draw down ponds to concentrate fish and facilitate collection also will exacerbate depredation problems.

Habituation is a key factor influencing the effectiveness of a predator control method. Habituation is a process where an animal's normal fright response to novel situations gradually is extinguished so long as the

stimulus poses no real threat to the animals (129). To remain effective, a stimulus must

be increased in intensity or altered in presentation. Many commonly relied upon techniques have limited effectiveness as predators "learn" that the devices do not pose a real threat. In other cases, the animal finds ways to circumvent the device and continue preying on cultured stocks. Examples of habituation include instances where predators learn how far to move to be out of range of noise-making devices and how to hunt from atop automatic exploders (e.g., moving away as the cannon discharges and returning shortly after to resume hunting).

The following paragraphs present brief descriptions of possible methods to control predators at aquaculture facilities. Unless otherwise noted, the information is summarized from an OTA contract paper on predation in aquaculture (107).

Facility Siting and Design

Decisions relating to the siting and design of a new aquacultural facility should be based, in part, on reliable information about potential predation problems. Developers should make a conscious effort to avoid constructing aquacultural facilities on known migratory routes, near well-established rookeries, or near areas where fish-eating birds concentrate (147). Facility design also should incorporate predation deterrents. Incorporating workable predator management technologies in the initial stages of construction may reduce lower economic losses once the facilities are operating.

Good Husbandry

The use of sound husbandry practices in any aquacultural facility plays an important role in minimizing problems with predators. Simple, common sense activities such as properly storing and cleaning up spilled feeds, regularly removing and properly disposing of dead or dying stock, and controlling the growth of vegetation around holding structures could provide substantial benefit by making a site less attractive to predators.

Non-Lethal Control Methods

Non-lethal control methods for predators of aquaculture facilities include modifications to facilities and to operational procedures, harassment techniques, barriers, live-traps, and chemical deterrents. Aquaculture facilities may be made less attractive to predators if water depth or slope of pond embankments is increased. Use of non-floating feed, and locating vulnerable stocks close to the center of human activity where predator activity may be lowest, also can be helpful.

Harassment involves using auditory or visual techniques to trigger a fright response. Auditory harassment techniques include automatic exploders and predator distress calling (a broadcast of a recording of a call emitted by an animal in response to alarm). Visual harassment techniques include lights, scarecrows, and human or animal presence to harass birds and prevent them from landing.

Several types of barriers may prevent or deter predators. Fencing or netting may be installed around the perimeter of a facility, or water spray devices may distribute jets of water over the water's surface to provide both visual and auditory stimuli. The cost of the barrier and the size of aquaculture facility will dictate the feasibility of a particular barrier.

Trapping a predator may require a state and/or federal authorization. Where legal and appropriate authorization has been obtained, several types of cages and box traps enable capture of live and uninjured animals. The trapped predators can then be transported away from the aquaculture facility.

Some chemicals may be used to deter selected avian predators from ponds. One such product has a plant derivative base with a grape-like odor (methyl anthranilate,

MA). Various formulations of MA form a coating on the water surface that avian predators find unpleasant. These been tested under controlled pen conditions with captive birds and under field conditions in culture ponds. Experimentation continues on developing formulations and applications suitable for use in commercial aquacultural operations. Concerns with use of chemical deterrents in aquacultural operations include human health and safety issues (e.g., potential for chemical contaminants in consumable foods) and the possibility that foul-tasting substances may make the cultured organism unpalatable to humans as well as other predators.

Lethal Control Methods

Use of lethal technologies in wildlife management follows a decision to kill animals causing damage to property (142). Lethal methods may include trapping and killing, using toxicants, or shooting. Traps to capture and kill birds in aquacultural facilities have been used historically (up to the early 1970s); however, no recent studies document use of traps on fish-eating birds. Many states have regulations prohibiting the use of toxicants or poisons on nuisance animals. The potential for non-target losses and secondary hazards usually preclude their use except under carefully controlled applications. Some facilities employ personnel to "ride shotgun" around ponds specifically to harass and shoot birds.

BIRD DEPREDATION PERMITS

To shoot most predatory birds, an aquaculture facility owner must obtain a bird depredation permit (box 4-4). Information on number of depredation permits issued and total take of protected species under such permits is collected by the Regional Offices of the USFWS, Division of Law Enforcement. Depredation permits are applicable to a wide spectrum of wildlife conflict areas and, thus, are not restricted to problems experienced in aquacultural facilities.

Data on take of birds often are not separated by specific commodity area, making summary information for aquaculture not readily available. The retrieval system established by the regional offices was designed primarily to facilitate their internal tracking of the names and locations of permittees, when permits were issued, and the species for which the permit covered. Data on the results of actions taken by a permittee under the provisions of their permit are contained only in annual reports filed by the permittee with the regional offices; in most instances, this information is not computerized and retrieval is made only by reviewing each report manually.

Summary data provided to OTA from the USFWS, Division of Law Enforcement, Regional Offices on permits issued, thus, came in differing and sometimes incompatible data sets, precluding exact summarization. For example, some regions reported data over varying periods of years, Region 4 did not report any permits before 1985, and Region 7 did not provide any data, replying "no activity" (figure 4-1). In light of incomplete data sets and a poor retrieval system for reviewing permit records, the following remarks must not be viewed as conclusive.

A total of 51,553 birds representing 38 species or groups of species were taken by permittees at aquacultural operations nationwide between 1989 and 1993 (table 4-2). Double-crested cormorants (25,930 birds or 50.3 percent of total take), great blue herons (9,443 birds or 18.3 percent of total take), and great egrets (4,242 birds or 8.2 percent of total take) were taken most frequently according to reports filed by

Figure 4-1. U.S. Fish and Wildlife Service Regions

Region 1: California, Hawaii, Idaho, Nevada, Oregon, Washington, American Samoa, Commonwealth of the Northern Mariana Islands, Guam, and the Pacific Trust Territories; **Region 2**: Arizona, New Mexico, Oklahoma, and Texas; **Region 3**: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin; **Region 4**: Alabama, Arkansas, Louisiana, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Florida, Tennessee, Puerto Rico, and the U.S. Virgin Islands; **Region 5**: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, and West Virginia; **Region 6**: Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, Utah, and Wyoming; **Region 7**: Alaska

BOX 4-4: Bird Depredation Permit Process

The U.S. Code of Federal Regulations, title 50, includes six sections: two depredation permit processes (sections 21.41 and 21.42), and four special "standing depredation orders" where a permit is not required to take birds (sections 21.43-21.46). Section 21.41 allows the USFWS, Division of Law Enforcement, to issue kill permits for the take of protected species. Section 21.42, which allows the take of migratory game birds deemed responsible for serious economic damage to agriculture--including aquaculture--stipulates that a depredation permit must be issued by the Director of the USFWS before take occurs.

The four standing depredation orders, where an individual permit is not required, are quite specific: Section 21.43 relates to the take of selected species of grackles, blackbirds, magpies, and crows causing physical damage to agricultural/livestock operations, wildlife, or ornamental and shade trees or where numbers of these birds present a nuisance or health hazard; section 21.44 is limited to the treatment of passerine (non-perching birds such as woodpeckers) damage in California; section 21.45 allows for the take of purple gallinules in Louisiana rice fields; and section 21.46 provides protection against depredation by jays to commercial nut crops in California and Washington.

The U. S. Fish and Wildlife Service, Division of Law Enforcement (in consultation with field personnel of USDA's Animal and Plant Health Inspection Service, Animal Damage Control), administers, maintains records on, and enforces compliance with section 21.41 depredation permits. Persons wishing to obtain a depredation permit must file an application with the Division of Law Enforcement's regional office serving the applicant's geographic area (there are seven regional offices). The application must describe the following: 1) the species for which a kill permit is desired; 2) the site where damage has occurred; 3) the type of damage inflicted; 4) an estimate of the amount of damage incurred; and 5) a demonstration that all reasonable efforts have been made to stop the damage through use of non-lethal technology.

Permits issued to individuals may cover an entire year (typically those permits issued to a federal or state facility) or have a fixed time period within which authorized take may occur. Permits should stipulate the number of individuals and the species that can be taken. When a permit expires, the issuant is required to file with the Regional Office a report that describes the species and number of individuals actually taken under the provisions of the permit. Failure to prepare and submit an annual report usually prevents the applicant from receiving another permit in the future. The carcasses of any birds taken do not necessarily have to be surrendered to federal authorities, but leg bands and other data pertinent to marked individuals must be reported to the USFWS Migratory Bird Laboratory. In some cases, depredation kill permits have been issued as a means of achieving a temporary reduction in predation pressure while other non-lethal techniques can be put in place.

In most states, regulations also exist that afford protection to non-game species (i.e., those for which a regulated season does not exist) and special permits from the state wildlife agency are required to take such birds. As is true under stipulations of the federal statute, applicants must show good cause to justify the need for removing such animals using lethal means. Reporting requirements similar to those of the USFWS exist at the state level.

SOURCE: Office of Technology Assessment, 1995.

permittees with the USFWS. Other birds taken in relatively high numbers included snowy egrets (1,208 birds, 2.3 percent of total take), little blue herons (1,379 birds or 2.7 percent), black-crowned night herons (1,734 birds or 3.3 percent), ring-billed gulls (1,050 birds or 2.0 percent), and belted kingfishers (1,197 birds or 2.3 percent).

Authorized take of birds by permit from 1989 to 1993 was greatest in Region 4 (34,698 birds or 67.3 percent of total take), followed by Region 6 (7,985 birds or 15.5 percent), Region 1 (3,915 birds or 3.0 percent), and Region 2 (1,050 birds or 2.0 percent). As reflected by data on reported kill, cormorants, wading birds, gulls and terns, and selected species of waterfowl appeared to be troublesome for aquaculturists nationwide whereas other species or groups were problematic only

within a particular region (e.g., pelicans in Region 4; grackles in Region 6). Of all

TABLE 4-2: Reported authorized kill of bird predators at aquacultural facilities in the U.S., 1989-1993 (U.S. Fish and Wildlife Service, Division of Law Enforcement)

Species/Group	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Total
Swimming birds							
Grebes				708			708
Western Grebe	36					9	45
Pied-Billed Grebe						22	22
Pelican				225			225
American Pelican						19	19
Double-Crested Cormorant	1,494	824	1,356	19,620	1,514	1,122	25,930
Anhinga				42			42
Mallard						76	76
Common Eider					14		14
White-Winged Scoter	48						48
Old Squaw					7		7
Goldeneye						10	10
Merganser		52					52
Common Merganser	15					270	285
American Coot	75			363		37	475
Waders							
Egret			5				5
Great Egret				4,242			4,242
Snowy Egret	738			363		107	1,208
Heron	50	158		154			362
Great Blue Heron	350		122	7,295	136	1,540	9,443
Green-Backed Heron	6					13	19
Little Blue Heron				1,379			1,379
Black-Crowned Night Heron	662					1,072	1,734
Aerial-divers							
Gull	249			265			514
Herring Gull	2		28		631	186	847
California Gull						364	364
Ring-Billed Gull	8		13			1,029	1,050
Franklin's Gull						17	17
Bonaparte's Gull						17	17
Forster's Tern						285	285
Common Tern						38	38
Caspian Tern	175					3	178
Great Horned Owl						18	18
Belted Kingfisher	7	16	18	42	61	1,053	1,197

TABLE 4-2: Reported authorized kill of bird predators at aquacultural facilities (cont'd.)

Species/Group	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Total
Common Raven						93	93
American Crow						14	14
Common Grackle						391	391
Total	**3,915**	**1,050**	**1,542**	**34,698**	**2,363**	**7,985**	**51,553**

NOTE: Some species were identified without full common name in USFWS data
SOURCE: Office of Technology Assessment, 1995.

species, double-crested cormorants were taken most frequently in all regions except Region 6, where great blue herons topped the list.

The number of depredation permits issued to aquacultural operations nationwide has increased since 1980 (figure 4-2). The largest increases have occurred in Regions 3 and 4.[7] Although the national trend in reported kill of avian species at aquacultural facilities in the United States is increasing, a significant increase (+516.1 percent) in take of birds in Region 4, particularly in Arkansas and Mississippi, is driving this trend.[8] Of the 35 states in which depredation permits had been issued and for which reports of take were filed with the USFWS for the period 1989 to 1993, Arkansas led all states in total take (27,072 birds; 52.5 percent of national total); Mississippi ranked second in total take (5,295 birds; 10.3 percent of national total) (107).[9]

[7] Total number of permits issued remained stable or declined in Regions 1, 5, and 6; permits have increased only slightly in Region 2. States receiving noticeable increases in number of issued permits include Texas (up from zero in 1980 to 16 in 1994), Minnesota (up from two in 1979 to 44 in 1984), Arkansas (up from zero in 1985 to 55 in 1984), and Mississippi (up from zero in 1985 to 39 in 1994). Number of permits issued has declined in Washington (down from eight in 1980 to one in 1994), Maine (down from 14 in the 1980s to seven), New Hampshire (down from seven in the 1980s to zero in 1994), and Kansas (down from 10 in the 1980s to three).

[8] Nationally, 42,892 birds were reported taken under depredation permits issued to aquacultural sites during the period 1979 to 1989. In the following five-year period (1989-1993), 51,553 birds were reported taken (a 20.2-percent increase). Outside Region 4, however, the take of birds under permit appears to have declined, remained stable, or increased only slightly. For example, a comparison of five-year averages (1985-1989 vs. 1989-1993) in Regions 1 and 2 revealed a slight increase (+12.1 percent) and a major decline (-41.2 percent) respectively. There was a moderate increase in reported kill in Region 6. Unfortunately, because no other regions provided data on yearly take that would allow tracking of five-year averages, accurate prediction of trends is not possible.

[9] California (3,542 birds; 6.9 percent of national total) ranked third. Arkansas also led the nation in terms of take for selected species of birds: double-crested cormorant: 112,092 (58.2 percent of national reported take), great egret: 3,320 (78.2 percent of national reported take), great blue heron: 5,531 (58.6 percent of national reported take), little blue heron: 1,366 (99.0 percent of national reported take), and American coot: 342 (72 percent of national reported take). California led the nation in take of snowy egrets (738; 61.1 percent of national reported take), Nebraska led for belted kingfishers (569; 47.5 percent), and Utah was highest for black-crowned night herons (970; 55.9 percent).

States or territories not reporting any take of birds (or where depredation permits were not issued) between 1989 to 1993 included: Region 1: Hawaii, Oregon; Region 2: New Mexico; Region 3: Illinois, Indiana; Region 4: Kentucky, Puerto Rico, Virgin Islands; Region 5: Delaware, Massachusetts, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont, West Virginia; Region 7: Alaska.

Figure 4-2. Bird depredation permits issued to aquacultural facilities by U.S. Fish and Wildlife Service, Division of Enforcement, 1979-1994.[1]

[1]Data for all years for all regions were not available. Numbers were reported separately for some years and in groupings of years making direct comparisons impossible.

Data for some years were summarized as follows:

Region 1 1990-1994: 15 permits
Region 2 1991-1994: 25 permits
Region 3 1991-1994: 93 permits
Region 5 1980-1988: 41 permits; 1989-1993: 19 permits
Region 6 1980-1988: 38 permits; 1989-1993: 33 permits

Number of permits appearing in yearly total may include new permits as well as renewals of permits issued in previous years.

An entry into a year's total number of permits for a region may represent a permit issued to an individual to help address a predation problem at a single facility. Another entry into a region's yearly total of permits may represent a blanket permit issued to a state agency to address predation problems at all of the cultural facilities within that state. Although in each case only a single permit appears in the total, actual take may be occurring at as many as 10 or more sites. Thus, the total number of permits issued for a particular year may be a misleading indicator of the extent of activity actually occurring in the field.

TRENDS IN BIRD POPULATIONS

Only a small number of avian predators associated with aquacultural operations have demonstrated any documented and widespread changes in breeding, migration, or wintering patterns. This does not mean that such changes have not occurred for other species, or, that observed changes are due to aquaculture. In fact, it is highly likely that small scale, local shifts in avian activity patterns have occurred in response to specific catastrophic events or alterations in habitat. Documentation to support such a hypothesis, however, is scattered and not easily summarized for the number of species of avian predators concerned (107).

The Breeding Bird Survey (BBS), sponsored by the U.S. Fish and Wildlife Service and Canadian Wildlife Service, provides some indication of changing trends of bird populations (data from Patuxent Research Lab, Maryland). In brief, trained volunteers survey observation routes during the breeding season, counting species seen and heard. While providing valuable information on population status and trends, this data set may lack reliability. Potential sources of error include inclement weather, misidentifi-cation of species, and non-detectability of species. Thus, the following interpreta-tions, based on BBS data must be viewed with caution.

Using a 25-year summary (1965-1989) and a 10-year summary (1982-1991) of BBS data, OTA examined the population trends for eight species of birds commonly observed as predators of aquaculture farms: double-crested cormorant, great egret, snowy egret, great blue heron, little blue heron, black-crowned night heron, ring-billed gull, and belted kingfisher. In general, of these eight species, three experienced increases in populations in both the 25- and 10-year BBS summary periods: great egrets, snowy egrets, and ring-billed gulls. Two species experienced an increase in the 25-year summary period and had stable to decreasing trends in the 10-year summary period: double-crested cormorants and great blue herons. Three species experienced declines in both the 25- and the 10-year BBS summary periods: little blue herons, black-crowned night herons and kingfishers (107).

A cursory comparison of population levels with number of birds killed with depredation permits shows that most birds were killed in regions where populations are stable or increasing (cormorants, great egrets; great blue herons in Region 4; snowy egrets in California and Region 4; black-crowned night herons and ring-billed gulls in Region 6). Some areas with population declines issued no permits for the declining species (e.g., great egrets in Region 5) There are, however, several examples of birds killed in areas where trends in at least one of the two-summary periods show declines (e.g., cormorants in Maine; great blue herons in Region 6). Because of the uncertain completeness of the data on number of depredation permits issued, species and numbers killed and levels of populations in local and regional areas, none of these relationships can be considered conclusive. Thus, while speculation can be made on the effects of aquaculture on the population trends of some bird species (e.g., populations of some species increase as new food sources from aquaculture facilities become available), conclusive evidence is not available.

CONCLUDING REMARKS

Extent of loss to aquaculture facilities from bird predators is of great interest and concern to aquaculturists, researchers, and regulators. Lack of reliable information on predators responsible for losses and numbers and size of prey taken makes

reasonable approximations of economic impact difficult to determine.

There will, in all likelihood, never be one universal method that will resolve all conflicts between with wildlife and aquaculture. Aquacultural enterprises today are diverse in terms of facility design, practices, and types of organisms cultured. Even among facilities producing similar cultured stocks, differences in facility or site qualities, surrounding habitats, range and distribution of predators, and predator population densities reduce the likelihood that any one control technique will be effective in all situations.

A reasonable approach to a predator deterrent program may be to minimize damage to an economically tolerable level rather than to attempt complete control. Operators must be aware of the potential for adaptation and habituation in predators and develop plans to deal with these problems. Given currently available tech-nology, an integrated strategy that employs several deterrents used in rotation will provide the most long-lasting and effective means of limiting predation. Even under such an approach, operators must recognize that some losses will occur.

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Appendix B: Abbreviations

ACOE	U.S. Army Corps of Engineers (DOD)
ADC	Animal Damage Control (USDA)
AID	Agency for International Development (DOS)
AMS	Agricultural Marketing Service (USDA)
ANS	Aquatic Nuisance Species Task Force
APHIS	Animal and Plant Health Inspection Service (USDA)
ARS	Agricultural Research Service (USDA)
ASCS	Agriculture Stabilization and Conservation Service (USDA)
AVMA	American Veterinary Medicine Association
BPA	Bonneville Power Administration (DOE)
BRD	Bureau for Research and Development (AID)
BSD	Biofuels Systems Division (DOE)
BMPs	Best Management Practices
CCC	Commodity Credit Corporation (USDA)
CDBG	Community Development Block Grants
CFSA	Consolidated Farm Service Agency
COE	U.S. Army Corps of Engineers (DOD)
CRMP	Coastal Resource Management Program
CRS	Congressional Research Service
CRSP	Collaborative Research Support Program
CSRS	Cooperative State Research Service (USDA)
CSREES	Cooperative State Research, Education, and Extension Service (USDA)
CVM	Center for Veterinary Medicine (FDA)
CWA	Clean Water Act of 1977 (40 CFR)
DOC	Department of Commerce
DOI	Department of the Interior
DOD	Department of Defense
DOT	Department of Treasury
DOE	Department of Energy
DOS	Department of State
USDOTr	Department of Treasury
EDA	Economic Development Administration
EPA	Environmental Protection Agency

ERS	Economic Research Service (USDA)
ES	Extension Service (USDA)
ESA	Endangered Species Act
FACTA	Food and Agricultural Conservation and Trade Act of 1990
FARAD	Food Animal Residue Avoidance Databank (USDA program)
FAS	Foreign Agriculture Service (USDA)
FAS/ICD	Foreign Agricultural Service/International Cooperation and Development
FCA	Farm Credit Administration
FCCSET	Federal Coordinating Council on Science, Engineering, and Technology (OSTP)
FDA	Food and Drug Administration
FFDCA	Federal Food, Drug, and Cosmetic Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FmHA	Farmers Home Administration (USDA) (RDA's predecessor)
FOG	Financial Obligations Guarantee
FPPA	Federal Plant Protection Act
FSA	Farm Service Agency
FSIS	Food Safety and Inspection Service (USDA)
FWPCA	Federal Water Pollution Control Act
FWS	U.S. Fish and Wildlife Service (DOI)
GAO	Government Accounting Office
GRAS	Generally Recognized As Safe (FDA)
HACCP	Hazard Analysis Critical Control Point principles for seafood inspection
IIPR	Intentional Introductions Policy Review Committee of the ANS Task Force
INAD	Investigational New Animal Drug (FDA)
ISSC	Interstate Shellfish Sanitation Commission
IRS	Internal Revenue Service
IR-4	(assistance for chemical development for minor economic crops; now named NRSP-7)
JSA	Joint Subcommittee on Aquaculture (OSTP)
MMPA	Marine Mammal Protection Act
MPP	Market Promotion Program
MESP	Marine and Estuarine Sanctuary Program
NAA	National Aquaculture Act
NAA	National Aquaculture Association
NADA	New Animal Drug Application (FDA)
NADP	National Aquaculture Development Plan
NAL	National Agriculture Library (USDA)
NAIC	National Aquaculture Information Center (NAL/USDA)
NASAC	National Association of State Aquaculture Coordinators

NASS	National Agricultural Statistics Service (USDA)
NBIAP	National Biological Impact Assessment Program (USDA)
NBS	National Biological Survey (USDOI)
NCRI	National Coastal Resources Research and Development Institute
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service (USDC)
NOAA	National Oceanic and Atmospheric Administration (USDC)
NPDES	National Pollution Discharge Elimination Systems permits (authorized in CWA)
NRAC	Northeast Regional Aquaculture Center
NRC	National Research Council (NAS)
NRCS	Natural Resources Conservation Service
NRI	National Research Initiative
NRSP-7	National Research Support Project-7
NSF	National Science Foundation
OCRM	Ocean and Coastal Resources Management (NOAA)
OICD	Office for International Cooperation in Development (USDA)
OSHA	Occupational Safety and Health Administration
OSS	Office of Seafood Safety (FDA)
OSTP	Office of Science and Technology Policy (Executive)
RDA	Rural Development Administration (USDA)
RHCDS	Rural Housing and Community Development Services (USDA)
SBA	Small Business Administration
SBIR	Small Business Innovation Research Program (NSF)
SCS	Soil Conservation Service (USDA)
SDWA	Safe Drinking Water Act
SG	Sea Grant (USDC)
TSCA	Toxic Substances Control Act
TVA	Tennessee Valley Authority
UJR	United States-Japan (cooperative aquaculture program)
USDA	U.S. Department of Agriculture
USAID	U.S. Agency for International Development
USDOC	U.S. Department of Commerce
USDOI	U.S. Department of the Interior
USDOD	U.S. Department of Defense
USDOT	U.S. Department of Treasury
USDOE	U.S. Department of Energy
USDOS	U.S. Department of State
USFS	U.S. Forest Service (USDA)

USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey (USDOI)
USHHS	U.S. Department of Health and Human Services
USDOTr	U.S. Department of Treasury
WAS	World Aquaculture Society

Appendix C: Contract Papers

CONTEXT OF U.S. AQUACULTURE

International Seafood Trade and the U.S. Aquaculture Industry
Raymond Rhodes (South Carolina Wildlife and Marine Resources, SC)

Aquaculture--International Examples of Success and Failure and Lessons for the United States
Andrea Katz (Associates in Rural Development, Inc., VT)

Market Constraints to Growth in the U.S. Aquaculture Industry
Upton Hatch (Auburn University, AL)

Aquacultural Contributions to Community Development in the United States
Michael Skladany and Conner Bailey (Auburn University, AL)

TECHNOLOGIES, PRODUCTS, AND APPLICATIONS

The Aquaculture of Endangered and Threatened Species and Restoration of Aquatic Systems
Jack Rudloe, Jeret Madei, and Anne Rudloe (Gulf Specimen Marine Lab, Panacea, FL)

Offshore Aquaculture--Technology and Policy Issues
Robert Stickney (University of Washington, WA)

Policy Issues for Aquaculture in Federal Waters
Alison L. Hess (Office of Technology Assessment, DC)

The Future of Recirculating Systems in the U.S. Aquaculture Industry
Ronald Malone (Louisiana State University, LA)

Benefits, Environmental Risks, Social Concerns, and Policy Implications of Biotechnology in Aquaculture
Anne Kapuscinksi (University of Minnesota, MN)
Eric Hallerman (Virgina Polytechnic Institute and State University, VA)

Sustainable Aquaculture Systems
David Brune (Clemson University of South Carolina, SC)

INDUSTRY DEVELOPMENT AND REGULATION

Improving the Competitiveness of U.S. Aquaculture
Per O. Heggelund (AquaSeed, WA)

Successes and Failures in Aquaculture
Rollin Johnson (Harvard University, MA)

Health and Disease Management in Aquaculture: Science, Technology, and the Federal Role
Fred Meyer (La Crescent, MN)

Bird and Mammal Predation in Aquaculture
James Parkhurst (Virginia Polytechnic Institute and State University, VA)

Environmental Aspects of Commerical Aquaculture
Thomas Hopkins (Biometrics, Inc., MD)

GOVERNMENT POLICY AND PROGRAMS

Potential Sources of Federal Assistance for Aquaculture
Thomas Royal (St. George Island, FL)

U.S. Aquaculture Marketing
Howard Johnson (Johnson and Assoc., Bellevue, WA)

WORKSHOPS

The Future of Aquaculture in the United States--September, 1993

Offshore Aquacultural Development in the United States--November, 1993